(1) பக்கங்களின் எண்ணிக்கை ______________

(2) புதுக்கித் திருப்பிய நாள் ______________

(3) ஆதாரங் குறிப்பவர் சுருக்கொப்பம் ______________

தமிழ்நாடு ஆவணக் காப்பகம்

தமிழ்நாடு அரசு

______________ துறை

அரசாணை எண்.	அச்சகம்
மு. கோப்புத் தாள் எண்.	பலவகை
நாள்:	20 .

படிக்கவோ கண்டபடி கையாளவோ கூடாது.

ஆவண. கா. 1–182–2–20,000 Cps.–15–11–2019 [HCL-11]

…blic Works (1904) Department

SERIAL
No. 33

Confidential

G.O., No. 773 4 I.

Confidential

DATED 14 July 1904.

[Despatch Abstract.]

Report by Major A J De Lotbiniere R.E. on the utilization of the Periyar water for the development of electrical energy. Ordered that a copy of — be forwarded to the H.E. Treasury

Indexed

P.W. 26.
5,400—12-8-01.

Public Works Department.

Irrigation Branch.

Note for His Excellency the Governor.

Major de Lotbiniere's Report on the Periyar Power Scheme is submitted with the following remarks:-

Section 1. Major de Lotbiniere's estimate is for an installation capable of delivering 10,000 H.P which he proposes selling at £ 5-2-8 per H.P. (or say £ 5 per H.P.) and which he says would yield a clear profit of 5 %. Sold at this rate however it would only pay interest charges and the cost of annual maintenance and depreciation of plant. We could of course borrow money at a cheaper rate than that allowed but to show a clear profit of 5 % we should have to charge a good deal more for our power.

I suggested to Major de Lotbiniere that it would be better to prepare an estimate for an installation to deliver the whole of the power available, because with a smaller installation it would be impossible to show a profit seeing that the cost of our reservoir on the plains would be 35 lakhs whatever the size of the installation.

Major de Lotbiniere refers to this reservoir in his Note but his calculations are beyond ~~one~~ me

The reservoir will [illegible] the water not required for irrigation? The [illegible] would be [illegible] through the [illegible] turbines [illegible] depends on the [illegible] of power the market requires

Section 2. The electrification of the South Indian Railway promises well, but I am surprised to hear that only 2,500 H.P. will be required to electrify the line between Trichinopoly and Tuticorin

With regard to power at Madura I dont see why Messrs Harvey & Co, should get it at a cheaper rate than the Municipality.

It is quite possible that Mills will be erected near the generating station, in which case Major de Lotbiniere says we could give them power at £ 2 per H .P. How he arrives at this figure it is impossible to say.

Taking his estimate at end of Section 1 and omitting cost of transmission altogether, and reducing working expenses by 50 % we get

Annual working expenses.	£ 10,000
Depreciation of plant 5% on estimate cost(£ 1,84,000).	9,000
Interest on £ 283200 at 5 %.	14,000
	£ 33,000

so that if he sells 10,000 H.P. at £ 2 per H.P. the working expenses and interest charges would exceed the annual revenue by £ 13,000. In this case says Major de Lotbiniere "What would manufacturers gain" This is not an easy question to answer, but it is quite certain Government would lose heavily.

I am afraid Major de Lotbiniere has been indiscreet in suggesting that Government will be in a position to sell power at such absurdly low rates, and with -- reference to Messrs Binny & Cos letter I think it most unlikely that we shall ever be able to sell power in Madras at £ 7 per H.P.

It is possible the Govt would give the power for nothing or any price

Section 3. It is premature to discuss this till it has been decided to carry out the scheme.

Section 4. When the "single-phase system" has been completed, it may be possible to electrify a greater length of the South Indian Railway.

General remarks. I think Major de Lotbiniere should be asked to let us have an estimate for an -- installation capable of delivering the total amount of power which can be generated.

I think his report shows that there will be a certain

market for the power. He should be asked to revise it in one or two places and I would then suggest sending it to the Secretary of State with a request that the best expert opinion at home might be -- obtained. The further action of Government in the matter would depend on this opinion being favourable or otherwise.

M.A.K.
28/6/04

C. [illegible]
28.6.04

I cannot understand how Major de L. set about this work without understanding that while the water power was there it could be used for electrical purposes only subject to its first use for irrigation ultimately. This was made clear enough in the "note" of Nov 97 & Appendix 1 of May 97: it is just this complication of using & not losing the water that makes the computation of expense difficult. What natural connection there is or can be between H.P generated & the cost of works to retain ~~that~~ the generating water I am unable to conceive, and the airy way in which Major de L treats the novelty

of the case in his note to Section
1 makes one apprehensive when the
sketchiness + ultra-enthusiasm of
the report itself are remembered.

I don't know if any of our Engg.
members knows much about Electricity
& its modern adaptations; but clearly we
can do nothing on this report till our
Chief Engineers and any Expert we may
possess meet + discuss the whole pro-
posal with Major de Lotbinière & give
Govt some digested advice in conse-
quence thereof. I am not aware of
how the cost of an impounding reservoir
is fixed at 35 lakhs; if it is pure guess
work it is not satisfactory. On the as-
sumption that the power will find a market
in full it will be necessary to estimate for
a full capacity reservoir, without inclusion

U
29.6.02

Public Works Department,

Irrigation Branch.

Circulated to

The Hon. Mr. G. Stokes, C.S.I.

The Hon. Mr. G. S. Forbes, C.S.I.

His Excellency would like to have the matter discussed at the next meeting of Council.

Major de Lotbiniere's report shows the existence of a market, but possibly the applications for power which are said to be coming in fast, would not be so numerous if such low rates had not been mentioned.

However if Government is satisfied that there is a market, the next point for consideration is the accuracy of the estimate.

In regard to this Major de Lotbiniere has omitted the cost of a pumping installation at the Periyar Lake, which is absolutely necessary, and without which it would not be safe to guarantee the continuous supply of 500 cusecs throughout the year.

In other respects the estimate is admittedly -- only a rough approximation, and like the estimate prepared by Colonel Pennycuick's Committee of experts might be very misleading.

Major de Lotbiniere's report shows however that it is worthwhile having a detailed estimate prepared, and for this work I would suggest that the Secretary of State be asked to send out an expert from home.

With an assured market and an accurate estimate, Government would be in a position to decide on the rates at which they could offer power, and whether the scheme would pay.

MRK 5/7/4

5-7-04

I have had a long talk with Mr Garrett today on the subject of these papers.

The first point, as it seems to me, which it is necessary to consider in this matter is the quantity of water available for power. In considering this we may for the present assume that there is to be no diminution of the quantity of water which is to be kept available for irrigation. After the reservoir has been enlarged it is assumed throughout these papers that 500 cusecs can be made available for power i.e. that a continuous supply of 500 cusecs can be made available throughout the year but in order to do this it will be necessary to make a reservoir at the foot of the hills or in the plains somewhere capable of storing all the water which is used for power in the three months of March April and May or about 4,500 million cubic feet at a cost of 35 lakhs and beside it will be necessary to provide a pumping installation costing 5 lakhs.

But all this is beside the present question really. This potentiality of power may be regarded as a reserve which can be utilised if worth while in future. In fact at present it is proposed in connection with the works needed for the surplus weir of the reservoir to raise the F.T.L. of the reservoir so as to increase its capacity by 2,360 million cubic feet. This quantity is sufficient to supply more than twice the amount of power which = 10,000 H.P. is needed for Major Lotbinniere's scheme as set out in these papers. And the conclusion at

2,360 million cubic feet will supply 297 cusecs for 92 days. 150 cusecs will give 10,000 H.P.

which we arrive therefore is that when the new works connected with the surplusing arrangements of the reservoir which it is practically certain that India will sanction as they were suggested by Sir T.Higham and are demonstrably necessary for the stability of the reservoir are completed an installation nearly twice as big as that contemplated by Major Lotbiniere can be established and run without in any way interfering with or trenching on the supply needed for all the irrigation contemplated ~~in the original scheme~~ without raising the F.T.L. of the reservoir not being raised and that by the special arrangements indicated above much more power can be made available. It seems obvious therefore that a scheme much larger than that outlined in the papers by Major Lotbiniere can be carried out on the basis of the present water supply without any ~~extra~~ other charge than those taken into account in his estimate. It is not necessary to add interest on 40 lakhs to be sunk in a storage reservoir on the plains and for a pumping installation at the lake.

~~The Chief Engineer~~ Mr Garrett thinks that Major Lotbiniere's estimate is untrustworthy. It is of course not a detailed estimate but I can not see any reason to think that it is very much out of the way. At any rate there is no one in South India who is capable of making a better estimate than Major Lotbiniere. But it is at the present moment of little ~~moment~~ importance whether the estimate is very accurate or not for it obvious that

This water might be let run and for power into the Vaigai. It may & no doubt will be thought be advisable for the purposes of irrigation to store it but that is an irrigation question & will only be justified by the extension of irrigation. Any expenses incurred for these under these circumstances should go against the irrigation project not against the power project. In this view it might strictly be necessary to take part of the cost of raising the F.T.L. against the power scheme but the loss is negligible.

the estimate might be nearly doubled and yet ~~for~~ the project ~~to~~ wd be remunerative, as the rate £ 5 per H.P. is ridiculously low. This is evident from what Major Lotbiniere himself says on pp.16 and 17 of his report. Mr Garrett tels me that they started with a charge of £27 per ~~£xxx~~ H.P. at Kolar and that the charge now is £15. There is a market capable of developement for the power in South India and I think there can be little doubt that the project will be remunerative.

But even if it were to be only little remunerative

A I think that it would so materially add to the resources and to the wealth of South India that it is incumbent on Govt to push it forward by all means in its power.

I think the action which we should now take is to forward the report to India and ask them if they will finance the project. If they will it will then be time to get the accurate estimate of the cost made and to make the detailed inquiries and to enter into the agreements with the users of the power to which Major Lotbiniere refers. As pointed out by him a special officer would have to be appointed for these purposes.

F.

6/7/14.

I agree generally with the Hon W Stokes conclusions - see portion marked A in his note - The first thing is I think to send

the report to India, & ask what their views are as to financing the project. They will take such other expert advice as they may deem necessary. Our letter to have to explain the connection bet. the irrigation & the electrical purposes of the Periyar water, & show how far the proposed works now under contemplation for irrigation needs can be utilized for the other duty. If India is favourable we sh^d suggest the employment of an expert to go into the details of the project.

S.F.
7/7

I/. The papers are to be discussed in Council tomorrow

M.R.K.
7/7/04

I agree to refer to India as proposed

[illegible]
8/7/04

Committee & returned.

[illegible]
9/7/04

No. 4 (b)—1000—30-3-04.

Public Works Department,

Irrigation Branch.

Note for His Excellency the Governor.

In accordance with the orders passed in Council on the 9th instant, a draft letter to India is --- submitted for approval.

MRR
11/7/14

12.7.04

11.7.04

Appendix 2. (Maps are being reproduced)

Government of Madras.

PUBLIC WORKS DEPARTMENT.

IRRIGATION BRANCH.

NOTE

ON

UTILIZATION OF WATER-POWER; PERIYAR PROJECT.

WITH APPENDICES.

MADRAS:
PRINTED BY THE SUPERINTENDENT, GOVERNMENT PRESS.

1898.

NOTE ON UTILIZATION OF PERIYAR WATER-POWER.

The Periyár lake is a large reservoir lately constructed by the Irrigation Department of Madras in the Travancore Hills which separate the Native State of Travancore from the Southern Presidency of India. The lake which is situated between 2,000 and 3,000 feet above sea level is formed by a masonry dam 155 feet high thrown across the valley of the Periyár river and by means of a tunnel through the watershed dividing Travancore from British territory, part of the flow of the Periyár is diverted from the well-watered land of Travancore to the comparatively dry district of Madura in British territory. This work is ably described in a paper by Colonel J. Pennycuick, C.S.I., R.E., read before the Institution of Civil Engineers in January 1897. Although undertaken primarily for irrigation purposes the situation of the work over 1,000 feet above the level of the plains on the British side lends itself favourably to the development of mechanical power and in 1892 Mr. A. Chatterton, Professor of Engineering of the College of Engineering, Madras, made a proposal to use the power for the manufacture of aluminium. In 1893 the subject of utilizing the water-power derived from the Periyár works was referred to a Committee composed of Professors Unwin, Forbes and Roberts-Austen and Colonel Pennycuick whose report is appended.

2. In addition to the proposal to utilize the power for the manufacture of aluminium, enquiries have been made with reference to the power being used for purposes of electric traction and for electric lighting and more recently the utilization of the power for the manufacture of carbide of calcium has been considered.

3. The latest decisions of Government on the subject are embodied in the appended notice calling for tenders for the utilization of the power, the date up to which tenders will be received having now been fixed as the 1st July 1898. Attention is directed to the second paragraph of the notice from which it will be seen that the quantities of water and head now taken to be available are different to those assumed by the members of the committee of 1893. Hitherto there has been no cause however to expect that the continuous available supply will ever fall to less than 500 cubic feet per second during the cultivating season.

4. A map of that part of the Madura district lying below the lake accompanies this note, as also a railway map showing the general situation of the lake and district with reference to towns and railways in this part of India.

5. The distance 6,800 feet given in the notice as that from the mouth of the tunnel to the foot of the hills is taken from a level section along the course of the stream from the tunnel, but it would probably be inadvisable to lay pipes along this line. The accompanying photograph shows the nature of this stream a little more than half a mile from the tunnel exit. The stream up to this point winds between hills densely covered with forest and descends in a series of cascades over sheets of rock and large boulders with which its course is strewn. The fall in the stream at the bridge from the tunnel exit is 305 feet. When the view was taken, the Periyár lake was one foot above full lake-level, and the tunnel was discharging full, the flow in the stream being calculated at 1,040 cubic feet per second.

6. Below the bridge the course of the stream is similar to that above until it approaches the plains when it flows through a deep valley, the action of the water cutting away the soft soil and widening its course until a permanent channel has been obtained. The fall of 900 feet mentioned in the notice has been taken to the nearest ground on the river bank that is thought flat enough to build on conveniently but a considerably larger fall can be obtained by going further down stream. A site for works can be obtained about 2 miles south-west of the Kuruvanuth village shown on the map. Building stone can be obtained from the hills close by, limestone is on the spot, and excellent timber can be obtained at Thekady or from the neighbouring forests.

APPENDIX II.

Public Works Department, Madras.

REPORT

OF THE

COMMITTEE APPOINTED TO CONSIDER THE QUESTION OF THE UTILIZATION OF THE WATER-POWER

DERIVED FROM

THE PERIYÁR IRRIGATION WORKS.

PUBLIC WORKS, No. 6.
INDIA OFFICE, LONDON, *24th August* 1893.

To

His Excellency THE RIGHT HONOURABLE
THE GOVERNOR IN COUNCIL,
Fort St. George.

MY LORD,

In accordance with the request contained in your Public Works Letter, No. 14/3472, dated the 20th December 1892, steps have been taken in this country to obtain the best available professional opinion on the subject of utilizing the water-power which will be available on the completion of the Periyár Irrigation Works.

2. A Committee composed of the following gentlemen was appointed to consider the question :—

Professor W. C. UNWIN, F.R.S.
Do. G. FORBES, F.R.S.
Do. W. C. ROBERTS-AUSTEN, C.B., F.R.S.
Colonel J. PENNYCUICK, R.E.

3. This Committee have submitted a report, which I now forward for your Excellency's consideration, and for such action as may be possible in the development of this important undertaking.

• • • • •

I have the honour to be,
My Lord,
Your Lordship's most obedient, humble Servant,

KIMBERLEY.

7. The distance from Kuruvanuth to the nearest railway station (Ammayanáyakkanúr) is 78 miles. Periyakulam on this road has a population of 16,000 and Uttamapalaiyam and Chinnamanúr about 5,000 each and Butlagundai something more. The other places on the road are but small villages. The road however is the main road into Travancore.

8. The following are possible applications of the power available :—

Manufacture of carbide of calcium.
Do. do. of aluminium.
Electric traction on railways.
Cotton mills.
Electric lighting.

Of these possibly the first is most promising. The report of the Chemical Examiner on specimens of limestone obtainable at the places shown on the map is appended to this note. Charcoal can be manufactured from the timber of adjacent forests.

The only large towns within about 100 miles from Kuruvanuth are Madura 80 miles with a population of 80,000, and Trichinopoly 72 miles from Ammayanáyakkanúr, population 80,000. Tanjore with a population of 50,000 is 31 miles beyond Trichinopoly. The nearest seaport is Tuticorin 90 miles from Madura.

MADRAS,
November 1897.

(Signed) W. HUGHES,
Chief Engineer for Irrigation.

Appendices to this Note.

I. Notice calling for tenders published in *Fort St. George Gazette*, dated 15th June 1897.

II. Report of the Committee appointed to consider the question of the utilization of the water-power.

III. Photograph of stream from tunnel.

IV. Description of lime specimens. Extracts from Sub-divisional officer's report. Report and analysis of the Chemical Examiner.

V. Periyár Map.

VI. South Indian Railway Map.

APPENDIX I.

NOTICE.

WATER-POWER.

Periyar Lake—Madras Presidency.

Tenders are invited for the utilization of water flowing from the Periyár lake for purposes other than irrigation and not incompatible with the use of the water for drinking.

2. The irrigating season extends over nine to ten months, during which time the discharge is likely to be from 1,100 to about 500 cubic feet a second according to the demands for irrigation and the available quantity in the lake. Subject to the risk of interruption by accidents or drought, a supply can be given throughout the irrigation season. No supply can be guaranteed at other times, but, so long as water is available, the Government will be prepared to issue it in such daily quantities as may seem to it advisable with reference to the time which is likely to elapse before the supply is replenished by the setting in of the rains.

3. The fall from the tunnel to the foot of the hills is approximately 900 feet, and the distance measured along the course of the stream about 6,800 feet. One cubic foot per second falling 900 feet is estimated to produce over 60 effective horse-power.

4. Intending lessees should state the quantity of water required in cubic feet per second and the annual rent offered for each cubic foot per second. No rent will be charged for the first year from the date of the concession; for the second year the charge will be one-fifth, and an additional charge of one-fifth will be made every year until the full rent is reached. The whole or part of the concession may be surrendered on a year's notice being given.

5. Lessees will construct at their own expense, on plans to be approved by Government, all the weirs and other works required to divert the water from the river below the tunnel.

6. For further information, application may be made to the Chief Engineer for Irrigation, Madras, by whom tenders will be received up to 31st October 1897.

Ootacamund, 28th May 1897.

A. R. KNAPP,
for Joint Secy. to Govt., P.W.D., Irrigation Branch.

ENCLOSURES.

No. 1.

Report of Committee on Utilization of Water-power at Periyár Works.

It is clear from the facts laid before the Committtee that, on the completion of the works for the diversion of the Periyár river, a large amount of power will become available for industrial purposes, and that the development and utilization of this power will be of the greatest importance to the Government of India from an administrative as well as from a financial point of view.

The subject naturally divides into two main branches, firstly, the development of the power at the site of the works by suitable hydraulic apparatus, and, secondly, its utilization on the spot, or transmission to distant places at which it may be more effectively utilized, and the Committee are of opinion that the best method of dealing with these questions will be by separate notes, drawn up by the individual members of the Committee, whose technical knowledge and previous experience best qualify them to deal with the separate branches of the enquiry.

Unfortunately, at the last moment, Professor Unwin, being on the eve of his departure for America, thought it better to withdraw from the deliberations of the Committee, and has only been able to report very briefly on the hydraulic arrangements for the development of the power at the site of the works, a subject with which he was eminently fitted to deal, and an additional note on this point has therefore been drawn up by the Chairman of the Committee, Colonel Pennycuick, R.E.

The notes of individual members are attached to this report, and a reference to them shows that the development of the power at the site of the works would not cost more than 4*l.* per horse-power for the hydraulic apparatus alone, and that the electrical apparatus for its transmission to Madras would not cost more than 35*l.* per horse-power delivered at that city, while for the towns of Madura and Trichinopoly the cost would be not more than 23*l.* and 17*l.*, respectively, the most important item of the cost of transmission being that of the conductors, which depends directly on the distance.

Making due allowance for interest on first cost, and depreciation of plant, it appears that power can be delivered in the three towns named at an annual cost per horse-power of 3*l.*, 2*l.* and 1*l.* 10*s*, respectively, and, comparing this with the cost of steam-power, there would seem to be every probability that a large portion of the available power can be profitably used in the towns in question as well as in the smaller towns on the road thereto.

The most obvious, and probably the most profitable, mode of utilizing a large portion of the power would be for the lighting of the towns within reach. The Committee understand that none of these towns are supplied with gas, and that in Madras especially the cost of lighting by oil lamps forms a considerable portion of the municipal expenditure.

The information before the Committee as to the nature of the corundum deposits of Southern India is insufficient to enable them to form a positive opinion as to the advisability of using any large amount of power in the manufacture of aluminium, but it is certain that the estimates contained in Mr. Chatterton's original memorandum were over-sanguine.

It is probable that a substantial amount of power might be usefully employed in the immediate neighbourhood of the works in the driving of wood working and cotton machinery. No cotton is believed to be grown in the immediate vicinity of the works, but large quantities are said to be produced in the neighbouring districts of Coimbatore and Tinnevelly, in both of which districts large mills are at work. The advantage of cheap power would probably more than cover the cost of carriage of the raw material to and from the site of the works.

The Committee concur in the opinion expressed by the Chief Engineer to the Government of Madras, that the water should be brought to the hydraulic motors by means of pipes, a separate pipe being used for each motor, or two motors at most being supplied from a single pipe, and that, with a view of reducing as far as possible the cost of the pipes, the fall should be divided into either two or three stages.

They do not consider that it is absolutely certain that it would not be found possible to convey the whole of the water to the foot of the fall by a single inclined shaft sunk through the rock, and if such a course were practicable its cost would probably be somewhat less than the cost of pipes, but they do not think that the chance of a saving in first cost is such as to justify the heavy initial expenditure involved in the detailed examination of the rock which would be necessary before the construction of the shaft could be undertaken. They also observe that the shaft must be constructed once for all for the whole quantity of water likely to be ultimately brought into use, while the pipes can be put down from time to time, as the utilization of the power is developed.

The Committee also concur in the Chief Engineer's opinion that the construction of a railway from the nearest point of the South Indian Railway to the site of works, a distance of about seventy miles, is a necessary preliminary to the utilization of the power in question. How far such a railway could be expected to pay interest on the cost of construction from ordinary traffic is a point on which the Committee have not sufficient information to enable them to form an

opinion, but looking to the fact that the greater part of the line will pass through country already fertile or about to be fertilized by the irrigation from the Periyár, and that it will connect the second largest town in the Madura district with existing lines of railway, they think it improbable that the deficit will be such as to outweigh the advantages to be gained by the utilization of the water-power under consideration. Such a railway might be easily and economically worked by electricity, for which it would be especially suitable, as for many years to come it must remain an isolated line, connected with other lines only by the single junction with the South Indian Railway at Ammayanáyakkanúr.

In the note of the Chief Engineer to the Madras Government, dated 17th October 1892, it is said that provision must be made for closing the head sluices at the Periyár for a fortnight in every year for the purpose of inspection and repair. Such closing would be a very serious obstacle in the way of the utilization of the power for electric lighting or for the working of railways; whether it can be avoided is a matter for the consideration of the professional advisers of the Madras Government, but the Committee are informed by their Chairman that he thinks there would be no serious difficulty in so arranging the sluices that a certain minimum quantity of water could be sent down at all times, and that the cost of such an arrangement would be insignificant as compared with the importance of the object in view.

It does not appear to be within the province of the Committee to offer an opinion as to the exact course to be adopted in order to bring into use the power under consideration. It is for the Government of Madras to consider whether they will themselves construct the whole or any portion of the apparatus necessary for the purpose, or whether they will simply lease the right to the use of the water to one or more contractors leaving the latter to make their own arrangements for its utilization.

The Committee would, however, suggest that early steps should be taken for giving the utmost possible publicity to the fact that this power will shortly become available, with a view to the submission of practical proposals for its development.

It must be borne in mind that there is a great probability of new industries being attracted to the district by the mere existence of a source of power, which appears to the Committee to be one of the cheapest in the world.

JOHN PENNYCUICK, Colonel, R.E.,
Secy. to the Govt. of Madras, P. W.D.

GEORGE FORBES,
W. C. ROBERTS-AUSTEN.

13th July 1893.

No. 2.

Note by Colonel PENNYCUICK, R.E., on the Hydraulic Apparatus required for developing the Water-power of the Periyár River, dated 28th June 1893.

It may be taken as certain that the water required for driving the hydraulic motors will be brought to the latter by iron or steel pipes, a separate pipe being provided for each motor, or pair of motors, and that no attempt will be made to carry the whole of the water-supply by a single shaft or inclined tunnel sunk in the rock on the sides of the valley down which the water is passed.

The side slopes of the valley are such that there will be no difficulty in laying the pipes with a slope of $2\frac{1}{2}$ or 3 horizontal to one vertical, and the average length of the pipes may be taken at three times the head.

The total fall available is a little over a thousand feet, and as a small amount will be lost at each stage if this total fall be divided into two or more stages, the effective head may be taken without sensible error at a thousand feet.

So far as the pipes are concerned, the cost per unit of power is pretty nearly independent of the size of the pipes for any given velocity and head. The power that can be conveyed by a single pipe varies as the square of the diameter, while the cost varies as the diameter multiplied by the thickness, and as the latter varies as the diameter for a given pressure, the cost varies in the same ratio as the power. In reality the cost is rather less for large pipes than for small ones, as the loss of head to produce a given velocity is greater in the latter case than in the former. This difference is not of importance in pipes over two feet in diameter.

The cost of the pipes is, however, very seriously affected by the number of stages into which the total fall is divided. Thus, a pipe three feet in diameter utilizing the fall of a thousand feet in a single stage would require a thickness at the bottom of about an inch and a half, and a mean thickness of seven-eighths of an inch. If the fall were divided into two stages the maximum and mean thickness would be three-quarters and half-an-inch; for three stages they would be one-half and three-eighths, and for four stages three-eighths and five-sixteenths, showing a reduction of thickness, and consequently of cost, in the proportion of 14, 8, 6 and 5.

On the other hand, there is a certain loss of head at every stage, the cost of the head-works and regulating gear is practically independent of the height of each stage, and therefore increases directly with the number of stages; and the cost of three turbines of a thousand horse-power would be considerably greater than that of a single turbine of three thousand horse-power.

The exact number of stages which would give the most economical result will vary according to the size of the pipe and the velocity allowed, but within the limits with which we have now to deal, it may be said broadly that there is considerable economy in an increase from one stage to two, not much in an increase from two to three, and little or none in any further increase. The further calculations in this note will be made on the assumption that the fall is divided into two stages of five hundred feet each, the pipe for each stage being fifteen hundred feet long.

The velocity of discharge permissible in the pipes exercises a most important influence on the cost of the latter per unit of power, the absolute cost being independent of the velocity, while the power transmitted increases in direct ratio thereto, except that the loss of head required to generate the velocity increases somewhat rapidly in proportion to the latter. Taking, as an example, the case of a three-foot pipe fifteen hundred feet long, with a total fall of five hundred feet, the result for different velocities would be—

Velocity per second.	Loss of head.	Effective head.	Horse-power.
	FEET.		
$2\frac{1}{2}$	1	499	727
5	4	496	1,446
$7\frac{1}{2}$	9	491	2,148
10	15	485	2,829
$12\frac{1}{2}$	22	478	3,485
15	32	468	4,095

the cost of the pipe being the same in each case.

The economy of high velocities is more marked in the case of larger pipes and less so with smaller ones.

So far as mere economy in the cost of the pipes is concerned, velocities of fifteen or even twenty feet per second might be used with advantage, but there are practical objections to the use of velocities much exceeding ten feet per second, and this limit will be adopted in the following calculations.

In Professor Forbes' report on the electrical transmission of power the unit is taken at 5,000 horse power. To generate this power on a fall of five hundred feet about 120 cubic feet of water per second would be required, which would be carried by a pipe four feet in diameter with a velocity of between nine and ten feet per second. The pipe would have a mean thickness of five-eighths of an inch, and would weigh 392 lb. to the foot, including an addition of twenty-five per cent. for joints, etc. The total weight would be $262\frac{1}{2}$ tons, and the cost at 20*l.* per ton 5,250*l.*, to which must be added 2,500*l.* for carriage to the site of the works, and 600*l.* for laying, making the total cost of the pipe, 8,250*l.*

A turbine to generate 5,000 horse-power would cost about 6,000*l.*, and 750*l.* might be added for a proportional share of general expenses, making the total cost of the installation 15,000*l.*, or 3·00*l* per horse-power.

The annual cost might be reckoned at—

	£
Interest 4 per cent. on 15,000*l.*	600
Maintenance	600
Depreciation 6 per cent. on 6,000*l.*	360
Total ...	1,560

or 0·312*l.* per horse-power.

The above calculations are for units of 5,000 horse-power, but for most purposes much smaller units would be preferable, and even for the electrical transmission of power I am inclined to doubt whether so large units would be advisable. Professor Forbes' calculations show that the principal item in the cost of transmission is that of the conductors, which is independent of the size of the unit of power, and that the increase in cost of the dynamos and transformers involved in the use of smaller units would not greatly increase the total cost per horse-power.

A pipe two feet in diameter, with a velocity of ten feet per second, would carry thirty-one cubic feet of water per second, and would have an effective head of 476 feet, and generate 1,230 horse-power.

Its mean thickness would be three-eighths of an inch, its weight per foot 110 pounds, its total weight 79 tons, and total cost, including laying, about 2,500*l.* The turbine would cost 1,600*l.*, and the total cost of the installation would be about 4,400*l.* for twelve hundred horse-power, or 3·67*l.* per horse-power.

The annual charge would be—

	£
4 per cent. on 4,400*l.*	176
6 per cent. on 1,500*l.*	90
Maintenance	200
Total ...	466

or about 0·39 per horse-power.

It is clear that whatever units were employed the capital cost would not exceed 4*l.*, or the annual charge about ten shillings per horse-power.

In a former note on this subject submitted to the Government of Madras, I advocated the use of Pelton wheels as the prime-movers for the generation of power. The Committee's discussions appear to have established the conclusion that these machines are not, in their present form at all events, suitable for electrical work on a large scale, owing to their want of regularity in speed and the fact that they work on a horizontal axis; the first defect I have no doubt might be got over by the use of an appropriate governor, the latter is fatal unless the machine could be modified so as to work on a vertical axis. In the estimates given above it has, therefore, been assumed that horizontal turbines will be used, but for power to be used on the spot and for purposes for which the extreme regularity of speed required for electrical work is not essential, it might be possible to use the Pelton wheel, and, if so, its simplicity and cheapness would be important advantages.

The calculations of cost given above refer to the maximum power of each motor; as the latter would probably never be worked up to its full power for more than a portion of each day, longer or shorter according to the work to be done, the real cost per actual horse-power would be somewhat greater than that indicated by these calculations. For example, the annual cost of a twelve hundred horse-power machine is calculated at 466*l.* If such a machine worked for ten hours daily at an average rate of a thousand horse power for three hundred days in the year, the annual cost per horse-power at the site of the works would be 0·47*l.*, and the cost per horse-power hour (the most accurate way of stating cost) would be about one six thousand four hundredth part of a sovereign or about one four hundredth of a rupee. The cost of a horse-power hour delivered electrically at Madras, Trichinopoly, or Madura would be one-seventieth, one one-hundredth, or one one-hundred and thirtieth of a rupee.

Inasmuch as the cost of steam-power at any one of these places is certainly not less than a tenth of a rupee per horse-power hour the highest of these rates would leave an ample margin of profit while the price at the site of the works would be so small as to offer every encouragement to the establishment of factories, even at a considerable cost for carriage of raw material and manufactured products.

The question of how far Government should be connected with the operations for the development of this power will need careful consideration. It must, in any case, construct the service reservoir and regulating works for the distribution of the power to the different prime-movers, unless the whole power is to be leased to a single speculator, a course which the Government will probably be unwilling to adopt; but the cost of these works, the designs for which can be drawn up by the local Public Works Department, will be trifling, probably not more than Rs. 20,000 for the first ten thousand horse-power and one rupee per horse-power for subsequent additions. On the other hand the Government will probably be unwilling to take any part in the transmission of the power to a distance or in its utilization for industrial purposes, and will either construct the pipes and prime-movers and lease the power derived from them, or lease the water direct from the service reservoir leaving the lessees to utilize it as they please.

A charge of sixty rupees in the former case or of thirty rupees in the latter per million cubic feet (with five hundred feet fall) would give a substantial addition to the returns from the Periyár and be almost unfelt by the users of the power. There would be no difficulty in controlling and recording the water used by such motors so as to enable the charges to be properly levied.

It is stated in the report of the Committee that it is proposed to modify the designs of the Periyár sluices so as to avoid the necessity of shutting off the water entirely for examination or repair of the head works. This is a most important point and the alteration will not add more than five or six thousand rupees to the cost of the sluices.

In the note submitted to the Government of Madras to which allusion has been already made, I remarked that having in view the progress made of late years in the electrical transmission of power, it was by no means certain that it would not be possible in the immediate future to utilize the power of the Periyár water for the lighting of Madura, Trichinopoly, or even Madras itself.

The information supplied to the Committee by Professor Forbes shows that this anticipation was in rear of the facts rather than in advance of them.

No. 3.

Preliminary Memorandum by Professor UNWIN, F.R.S., dated 20th June 1893, on the Periyár Project.

The data given me are that there is a supply of 600 cubic feet of water per second all the year round with an available fall of 1,200 feet. This would yield 60,000 effective horse-power. The only drawback mentioned is the stoppage of the flow for a fortnight annually for examination and repair of the tunnel and head works. This difficulty might, perhaps, be met by a service reservoir. For many applications the stoppage would not be a serious difficulty.

The first question is whether the fall should be utilized as a whole or in parts. With twelve hundred feet fall the pipes would be heavy. If the fall is divided the cost of machinery is increased. On the whole, I should suppose it best to divide the fall into two parts of six hundred feet each. I understand the slope of the ground to be about 1 in 4. Then for a fall of 600 feet the pipes would have a length of 2,400 feet.

The probability is that it will prove economical to make the pipes as large as possible. In America steel pipes of four and five feet diameter have been used under large heads. I think a four-foot steel pipe, double riveted for the lower part, and with transverse joints riveted up from end to end, would be suitable. With a larger pipe the flexibility gives trouble by causing leakage at the joints. I think the pipe should be laid in a trench and covered with earth to diminish the effect of changes of temperature which is liable to rack the joints and cause leaks.

Such a pipe would have an average thickness of about half an inch and a maximum thickness of five-eighths of an inch. It would carry 3,600 effective horse-power on 600 feet fall, and it would weigh about 280 tons. None of these quantities seem impracticable.

The pipe might supply two turbines of 1,800 horse-power each. Under the conditions any type of turbine might be adopted.

Generally for such a large quantity of water a pressure turbine is cheaper than an impulse turbine for equal workmanship and similar adjuncts. But probably conditions of speed imposed by the driven machinery may make it desirable to adopt some form of partial admission turbine. Girard turbines, like those at Terni, would be suitable, or, perhaps, tangent wheels could be more cheaply constructed, for a large power in the conditions at Periyár. Either form permits good speed regulation by a governor.

The Pelton wheel is suggested in the Public Works Department memorandum. But there is no experience in the use of Pelton wheels for so large a quantity of water. I have no reason for thinking that they would cost less than other forms of turbine in the conditions at Periyár. The Pelton wheel is most suitable when used with a single nozzle of small size. If a Pelton wheel of 1,800 horse-power had a single nozzle it would need to be 17 inches in diameter. If it had two nozzles they would have to be 12 inches in diameter each. It is true that Pelton wheels with multiple nozzles were proposed for Niagara, but the regulating arrangements were very crude and I am not aware that they have been tried. They do not seem to me to be so suitable or likely to be so efficient as other turbines.

The efficiency may not be important at Periyár with regard to saving water, but it is important in diminishing the cost of the turbine supply pipes.

Without more knowledge of the country, and the way in which the power is to be applied, it is impossible to make any but the roughest estimate of the cost of the hydraulic power. Further, the cost of transporting the machinery up-country and the probable cost of the excavation is not known to me. But I should think very possibly the cost might be between 5*l.* and 10*l.* per horse-power utilized (capital cost), or, I suppose, between 80 and 160 rupees per horse-power. That is for canals, pipes, turbines, and necessary buildings.

In any case, it appears that power can be obtained cheaply as to capital cost if any application can be found for it. I am disposed to think that the cost of the power would be a small fraction of the cost of electric machinery and transmission for applying it. Hence the problem at the Periyár is essentially a problem of finding an application for a very large quantity of power. The hydraulic part of the problem is the least doubtful and the least difficult. The distance of the site of generating the power from places where it can be easily applied is the most serious obstacle to be met.

No. 4.

Report (Revised) of Professor GEORGE FORBES, F.R.S., on the cost of developing the Water-power obtained from the Periyár Irrigation Works in the Madras Presidency, dated 7th June 1893.

Having been asked by the Committee to lay before our next meeting a report on the cost of the electrical part of these works, including the generation of electric current, and its transmission to certain points as yet undecided upon, and its utilization at these points, I have considered the matter very carefully, and, on attempting to make estimates, I have been met by the difficulty that there are many data about which I have no information. It is natural to suppose that the

machinery will be made in this country, and will be shipped out to Madras, from which point it will be carried probably by railway. If a railway be constructed over the distance from Madura to the Irrigation Works, this cost of transport need not be great; but if a preliminary plant has to be put down for a limited utilization of power, the cost may be considerable. I have no data as to the cost at which a pole line can be established for long distances to carry the large conductors necessary. If time had permitted I might have been able to confer with the telegraph department and get out accurate estimates in accordance with the requirements of the case. As it is, my estimates on these heads may be considered as purely approximate. It will be seen, however, that if we work on the lines I suggest, the cost of copper in the line is the principal expense and other matters are of comparatively small importance.

Conditions to be fulfilled.

The fall which will be utilized is sufficient to develop about 50,000 horse power on the shafts of the turbines. The first proposition is that this water-power should be developed by means of separate turbines, each of 5,000 horse-power. If smaller units be taken the cost per horse-power will be greater. The most successful working will be obtained from turbines with a vertical shaft, driving dynamos on the same shaft, each dynamo being of 5,000 horse-power. The points to which the electricity has to be carried by conductors vary from 80 to 350 miles. The purposes for which the electricity can be used are various. First, it can be used for the electric lighting of Madura, Trichinopoly and Madras, and possibly other places. This refers both to arc and incandescent lighting—arc lighting being suitable for open spaces, incandescent lighting being suitable for interiors, but being more costly. The electricity conveyed to a distance may also be converted into motive power for driving factories. It is possible that such factories might be attracted by cheap power to sites about 100 miles north of the irrigation works, and the same distance to the south-east, and perhaps in other places. The cheap power might attract cotton mills, and might start new industries, such as the refining of metals and extracting them from their ores.

Among these the production of aluminium by electrolytic processes immediately suggests itself, such processes having been successfully worked both in Europe and America. The uses to which aluminium is put are, at present, limited; but there is now a great effort being made to introduce it into several manufactures, and it is not impossible that the demand may increase considerably. It is worth pointing out the fact that the electrical conductivity of aluminium is very high, being twice as great as copper for equal weights of metal. Thus if aluminium could be produced at a cost of 1s. per pound it would be possible to compete with copper for electrical purposes. I have not the data to permit me to say with certainty whether this is possible or not, but information will doubtless be forthcoming, on the authority of Professor Roberts-Austen. A good deal has also been done in the production of other chemical substances by electrical action not in the domain of metallurgy alone.

In all these cases a continuous current of low electric pressure is required, whereas the current which is transmitted to a distance must necessarily be at high pressure. The transformation can be cheaply effected by using high pressure current to drive a motor, and having on the same shaft a low-tension generator of electricity, but there are several other methods concerning which I will report more fully at the proper time.

A field for the utilization of motive power developed by electricity which promises to be very considerable is that of electric traction. Nearly every city in the United States has its street cars or tramways worked by electricity, and several of the principal steam rail-roads have put down electric locomotives especially for dealing with the local work in their shunting operations with heavy freight trains, and for this purpose very powerful locomotives have been constructed. It is worth considering whether the demand for tramways in Madras is sufficiently great to make it likely that a development in this direction would be important.

The question is also well worth consideration whether the railways in the Presidency south of the town of Madras might not be advantageously worked by means of electric locomotives.

These being the general conditions that required to be fulfilled, I will now state the character of the machinery which seems to me best suited for carrying out these objects.

Character of Machinery.

The first point to be considered is the electric pressure at which the current is to be carried to the distant points. The higher the pressure the cheaper are the conductors required for transmitting the current; and since, in these cases of lighting and power transmission, the cost of conductors is one of the largest items of expense, it becomes a matter of the utmost importance to reduce this cost as far as possible, and this can be done by increasing the electric pressure to the highest limits which we can safely recommend.

The experiments of 1891, between Lauffen and Frankfort, showed that it was perfectly feasible to use 20,000 to 30,000 volts by means of overhead conductors. There were certain difficulties met with which we now know and appreciate, and which will always be avoided in the future. The Oerlikon Company, who were engaged in that experiment, are now putting

down a line 43 kilometres in length for an electric pressure of 40,000 volts. At Niagara Falls the electric pressure which we propose to adopt is 20,000 volts in the first place, with a possible increase as the work proceeds. I should say that, in the case of India, where the atmospheric conditions are favourable rather than otherwise, it would be safe to contemplate the employment of 30,000 volts or perhaps even 40,000, in the first instance, with overhead conductors. Such a system seems possible when we consider that the chief trouble in the higher latitudes with which I have hitherto had to deal arises from the effects of sleet and snow, and also that in the regions where these overhead poles will be set up, disastrous cyclones are not to be seriously feared. This is the cheapest way in which the line could possibly be laid.

Coming now to be generation of the current, the first thing which has to be decided is whether we shall adopt the continuous or the alternating current. The disadvantage of the former is that it has hitherto been impossible to construct a continuous current dynamo of high electric pressure successfully. This arises chiefly from the fact that a commutator is necessary in this class of machine. A second disadvantage of the continuous current is that there are no means of transforming the pressure without the use of moving machinery. It has sometimes been proposed to obtain a high pressure by connecting, in series, a large number of continuous current dynamos. For example, it has been proposed that each 5,000 horse-power unit should consist of 20 dynamos in series, each of 250 horse-power, giving 1,000 volts, making a total of 20,000 volts. No sound engineering scheme on these lines has been worked out. The expense is enormous, and the danger of handling such machinery would be very great indeed. With the alternating current, on the other hand, it is possible to generate the current directly at the extremely high pressures, which make transmission to great distances possible and economical; it is also possible to generate the current at low pressure, and then, by means of a transformer, to convert it into a current of high pressure for transmission over the line, and at the far end the pressure can be again reduced by a stationary transformer, and led into workshops, or elsewhere, or used for lighting purposes, at the moderate pressures which experience suggests. An alternating current dynamo is also about 40 per cent. cheaper than a continuous current machine of the same capacity, when dealing with large amounts of power.

Whether we consider the matter from the point of economy, safety, or certainty of uninterrupted supply, the alternating current has immeasurably the advantage. I could speak at much greater length on this point if thought desirable, but the point has been so universally conceded by the most experienced engineers, that it hardly admits of argument.

Assuming now that the alternating current is to be used, we must settle whether it is to generate current in a single phase, in two phases, or in three phases. The single phase alternating current is admirably adapted for all lighting purposes. Synchronising motors also work with a very high efficiency, but they require to be started mechanically so as to attain the synchronising speed before being put into circuit. Numerous alternating motors have been made with a single phase which start automatically, but hitherto they have not been largely developed, chiefly because there has been so little demand. Two-phase and three-phase motors start perfectly well on full load, and are quite as satisfactory as continuous current motors for ordinary workshop practice, and will serve for driving tramways or locomotives. They can be stopped, started, and reversed with the utmost ease. They have no commutator, nor collecting rings, on the revolving part, which is completely detached from the rest of the machine except at the bearings. The disadvantage of these multi-phase motors is that they require more than two wires. This is certainly a defect in distribution through a town, or in application to electric traction.

When alternating currents are being used for transmission, it is probable that the best way of using the power for traction purposes is to convert the alternating current into a continuous current at the place where it is used, by means of an alternating current motor driving a continuous current generator. Special machines have been constructed for this purpose which combine the motor and generator parts into one armature, an ordinary continuous current machine being used with insulated rings fixed round the commutator, four or three of them according as we are using a two-phase or a three-phase current brushes being fixed to rub on these rings as they revolve, the rings being attached electrically to commutator bars at equal distances round the periphery of the commutator. The two or three-phase currents being passed through these rings to the armature cause it to rotate, and the ordinary brushes of the continuous current machines take off continuous current, which serves to excite the field and which may be used for any purpose. Such machines have been constructed largely by Schuckert of Nurnberg, and to a certain extent by the two great American competing manufacturers of electrical machinery.

It appears, then, that the alternating current, either of one, two, or three phases, can be transmitted so as to develop power for motive power and for electro-chemical operations. Certain advantages have been claimed for the three phases. It has been said that the cost of copper in the conductors is less than with two phases. It has also been said that the turning power given to a motor is more uniform with three phases than with two. These claims are untenable.

It has also been said that the three-phase system requires only three wires and that the two-phase system requires four wires. This is not true. The two circuits of the two-phase system may be worked with a common return wire, and when this is done the copper required is less even than with three phases.

The three-phase system has the great objection that the three circuits must be inter-connected. This gives rise to a great deal of trouble in regulating the current, and also in testing the system for faults, and correcting these. The three circuits can never be at the same pressure, unless they are all loaded equally, and this makes the use of the system impossible for lighting purposes. I have made a number of tests on this point which I can lay before the Committee if desired. The single-phase and two-phase systems are free from these objections, and therefore I give them the preference.

The only question now is whether the single phase or the two phase is the best. For many reasons, I should be inclined to say that a single phase was the best, but the two-phase machinery develops two totally distinct currents, passing through different circuits, each of which can be regulated independently. It can also work multi-phase motors, the advantage of which has already been stated. The two-phase machine gives a larger out-put for the same weight of machinery than the single phase. For these reasons, I would, for general purposes, prefer the two-phase system; but this must depend largely on the character of the uses to which it is to be applied. If the circumstances are such as to yield readily to the adoption of a single-phase current for all purposes, I would be inclined to give it the preference. In the meantime, I propose to deal with the question as if we found it advisable to use two-phase machines, as this is more likely to prove to be the case.

Having now decided that alternating current, with 30,000 or perhaps 40,000 volts, and two phases, would be generated, it becomes necessary to consider what should be the frequency of alternations. This is a matter to which I have given great attention in the past year. I find that, for motive-power purposes, the lower the frequency, the better is the result down to about 10 periods per second; but when the current has to be used for electric lighting, whether arc or incandescent lamps, these low frequencies are not available. It appears, then, that by using a frequency of 50 we can work both arc and incandescent lamps, but the efficiency of our motors is sensibly reduced. I content myself at present with stating this result generally, instead of devoting, as I might, considerable space to showing the data on which I have arrived at this very definite conclusion. With any frequency under 50 periods per second arc lamps are found to flicker; with any frequency under 30 periods per second incandescent lamps are found to flicker disagreeably. If the chief use were for power purposes it would clearly be desirable to have the motors working at the greatest efficiency; and in this case I would recommend the adoption of a low frequency, somewhere about 10 or 15 periods per second, and the lighting would then be done, either by means of motors driving electric generators, or by means of some commutating machine, possibly like the one to which I have already referred. It seems to me probable, in the present case, that a very large amount of electricity might be used for the electric lighting of Madras, and if this is the case it might be best to put down the generators of such a character that they would do the lighting at the cheapest rate, and therefore have a suitable frequency. Motive power could still be efficiently supplied from these generators, although the efficiency of the motors would not be so high, and might only amount to perhaps 85 per cent.

On the whole, then, it might be assumed, for the present purposes, that we shall employ a current with a frequency of about 50 periods per second.

Since the pressure which we shall employ on the line is at least 30,000 volts, it becomes a question whether this ought to be generated directly in the dynamos, or whether the dynamos should give us a current of lower pressure, transformers being added for raising the pressure before the current goes into the line. This last method has been generally considered to be essential for very high pressures, but the additional expense of providing transformers is very great, the cost of transformers amounting in a number of estimates which have been before me to as much as the cost of the generators. If the dynamo be revolved about a vertical axis, and if the armature be fixed and the field magnets be made the rotating part, it becomes as easy to insulate the dynamo as it is to insulate a transformer, and the reduction in cost is very great. We thereby attain, also, an increased efficiency of the whole plant, and we avoid all trouble of introducing the extra self-induction which is involved by the employment of a step-up transformer. This design also enables us to put very considerable momentum into the revolving part, which serves to take up the irregularities due to the varying consumption of power in the moments while the turbine governor is adjusting itself to the varying load.

So far as it is possible to form a judgment without having fuller details of the purposes to which the transmission plant is to be applied, I would say that the above type of machine is what is required, having the following characteristics:—5,000 horse-power, vertical shaft generating 30,000 or 40,000 volts direct, frequency 50 per second, two phases. Such a machine can be got out at a remarkably moderate figure, and I can speak with confidence on this point from having had tenders for dynamos of this power from a number of different firms in Europe and America.

The cost of this dynamo may be taken at not over 6,000*l.*, but I find it impossible, at present, to estimate the cost of transport and fixing; nor can I estimate the cost of buildings until the designs of the turbines are submitted. These are all points which must be considered in detail when it is resolved to take further steps in the matter. The cost of transformers of 1,000 horse-power or over may be taken as certainly not over 1*l.* per horse-power, and I am of opinion that they ought to be constructed at half this price. The principal cost of the whole of this plant would lie in the line, owing to the great distances to which the current has to be carried, and to this point I shall now give some consideration.

The Line.

It is quite hopeless to deal with this project except by means of an overhead construction of the line. In many cases, depending on the climate, where heavy snow falls, sleet, and violent cyclones are encountered, an overhead construction is certain to lead to discontinuity in the service, but from what I have been able to learn of the climate in which it is suggested to put down this plant, there will be no serious trouble from this cause. I would therefore propose to put down a line of poles. These may be either of iron or of wood, in the latter case they should be made A shape for strength. It may be well, in considering the cost, to suppose that the line is laid out in units of 5,000 horse-power, but in some directions a much larger amount of power can be taken, and the actual cost in the poles will, in these cases, be less.

In the meantime I assume a set of poles for each 5,000 horse-power unit. The poles will be provided with special insulators, of which I can give details when required, embodying everything that has been learnt by past experience as to the troubles that have to be got over in this form of construction, and about the successful action of which there cannot be the slightest doubt. By this method of construction, in fact, I would have no hesitation in going up to an electric pressure of 40,000 volts, and this it would be most desirable to use in case it is proposed to go so far as Madras, whose distance from the irrigation works is 350 miles. It will be well to consider the cost of 40,000 volts carried to a distance of 350 miles.

In order to find out how much copper must be put into the conductors to give the most economical results, it is necessary to tabulate the results with different densities of current, and to compare the money loss in power wasted as heat in the conductors with the interest on the capital sunk in copper. It is necessary to select such a current density that, by a slight increase or decrease in this density, the additional gains and losses owing to difference in power wasted and in interest on capital sunk shall be equal.

If, however, there is no great prospect of so large a demand arising as to utilize all the available power it may be worth while to deliberately waste a considerable amount of horse-power, at a cost only of putting in turbines and dynamos, and wasting this power on the line by using much lighter conductors. In this way we shall arrive at a greater economy on the limited output, and I will work out the figures for the line to Madras.

The difference between these two ways of looking at the problem is this: in the one case we take the value of a horse-power as the selling value at the point where it is delivered; in the other case as the cost of production at the hydraulic works. It is extremely unlikely that the cost of this production of power would amount to more than 15*l.* per horse-power, which, at 10 per cent. per annum, would mean 30*s.* a year for the cost of producing a horse-power.

Having reference to what has now been stated, it will be best to examine what will be accurately the actual cost of the line at different densities of current on the long distance of 350 miles to Madras, assuming an electrical pressure of 40,000 volts. Accordingly I have computed the following table, in which the first column indicates the mean density of current reckoned in amperes per square inch. In the second column is given the cost of the copper per horse-power generated, the price being taken at 50*l.* a ton. The third column gives the horse-power that is lost on the line, and the fourth the remaining fraction of a horse-power that is available. The fifth column gives the cost of copper per horse-power delivered, and the sixth and last column gives the amount of horse-power that has to be generated at hydraulic works in order to deliver one horse-power at Madras:—

D.	Copper per horse-power generated.	Horse-power lost.	Horse-power left.	Copper per horse-power delivered.	Horse-power to be generated per horse-power delivered.
	£			£	
100	70	·08	·92	76	1·1
200	35	·16	·84	42	1·2
300	23	·24	·76	30	1·3
400	17	·32	·68	25	1·46
500	14	·40	·60	23	1·66
600	12	·48	·52	23	1·9
700	10	·56	·44	22·7	2·3
800	9	·64	·36	25	2·8
900	8	·72	·28	28	3·5
1,000	7	·80	·20	35	5·0

This table will be useful for general reference when we have obtained accurate data as to the cost of hydraulic works. The cost of the line, as indicated above, includes by far the greater portion of the total cost of the electrical plant. The electrical item of next importance is the cost of poles and insulators, which, for each unit of 5,000 horse-power, I have taken at 90*l.* a mile, being 1*l.* per pole and 2*s.* 6*d.* per insulator with its attachments, and I have taken 60 poles to the mile. It is probable that in dealing with larger amounts of power the cost will come out somewhat less. It is impossible to fix upon the best density of current to employ until we know the

cost of the hydraulic part of the works, because, as will be seen in the last column, when we reduce expenditure on the line we are increasing the amount of hydraulic power that requires to be developed. I will take a single case to illustrate the manner in which this table can be applied. Let us assume that a density of 400 amperes per square inch should be the most economical value. In that case we can include the main features of expense in the electrical part of the design. As I have stated above, the cost of a dynamo of the type which I have recommended would come to 6,000*l.* for a 5,000 horse-power unit, and the cost of a transformer I will take at 1*l.* per horse-power, although I am quite confident that this is considerably in excess of what we shall find in practice. I do not know how much to allow for cost of transport and erection, and that will be dealt with when the question of more detailed estimates arises. At that time also the small additional electrical appliances, such as switch boards and measuring instruments, may be considered.

The total cost of the principal parts of the electrical plant come out, on the assumption of a density of 400 amperes per square inch, as follows:—

	£
Copper on the line	25·0
Poles and insulators	6·3
Dynamos for 1·46 horse-power	1·75
Transformer for 1 horse-power	1·0
Per horse-power delivered, total ...	34·05

This is the cost for one horse-power continuously delivered at Madras. If we were dealing with the *lighting* of Madras only, the cost of line would refer to a *mean* (or more exactly the square root of mean square of current) output of one horse-power which would probably involve a maximum four times as much. The cost of dynamos and transformers would then have to be multiplied by four and the total capital would be 42·3*l.* for a *mean* output of one horse-power. This way of looking at it makes the electrical cost much more favourable when compared with steam, as the irregularity of lighting hours makes a steam plant very expensive to run.

To find the annual charge, it will be noticed that the copper conductors are permanent value, and it is sufficient to make a charge of 4 per cent. interest on this, while on all the rest of the plant we should make a charge of 10 per cent. for interest and depreciation. This gives the following annual charges:—

	£
Copper conductors	1·0
Poles and insulators	0·63
1·46 horse-power dynamos	0·18
1 horse-power transformers	0·10
Per horse-power delivered ...	1·91

This is for a continuous service. If the maximum demand were four times the mean, the cost would be 2·75*l.* per mean horse-power per annum, and during all the daytime most of this power could be diverted to other purposes.

I have taken this case of transmission to Madras as being likely to be a crucial case to determine whether a further consideration of the question is necessary, because it seems possible that in Madras there may be created a large demand for electricity both for the lighting of the houses and streets and also for working electric tramways. In the previous part of the report where I dealt with a distance of 100 miles, I assumed that we were working with a pressure of only 30,000 volts, but if 40,000 volts can be used for Madras, it can equally well be used to the shorter distances, and a corresponding economy would be thereby introduced.

It will now be asked whether I can undertake that these results can positively be accomplished. With regard to the cost of dynamos, I have gone at considerable length into a statement of the type of dynamo which I would recommend, and my principal object has been to so specify it that we shall be able to obtain such a dynamo at a moderate cost, and since the estimate which I have given is founded on estimates that have been given me for somewhat similar dynamos by a number of manufacturing firms, and as a percentage has been added to cover the extra cost of going to an insulation which will stand a pressure of 40,000 volts, I have no doubt that the cost given for the dynamos is well within that which we should be able to accomplish.

As to the cost of transformers, my estimate here is again in excess of certain estimates which have been received by me for another work where the transformers are built for large powers.

Concerning the price of poles and insulators, I have no hesitation in saying that in any country that I have had to consider in this connection, the work could be done at the price which I have named; but I have not the necessary information with regard to India to enable me to say with a certainty whether it is the case there also. All the machinery hitherto referred to, dynamos and transformers, can without a question be built so as to generate and utilize directly the electric current generated at the considerable pressure of 40,000 volts.

With regard to the line, I would not have any hesitation in saying that this would also be satisfactorily done if I knew that there were no special climatic conditions which may interfere with it. So far as I am aware, there are none such, and I therefore feel the utmost confidence that the line can be carried at the above pressure with freedom from interruption in the supply and with ordinary precautions there will be no danger. Since, however, as I have already stated experiments are at this moment being made in Switzerland, where a line is being tried over a distance of 43 kilometres and using a pressure of 40,000 volts, it will be interesting to follow the progress of this work, and as I have been promised an early account of the results, this information will be available and will be of considerable utility to us. I ought to mention that in the project for utilizing Niagara Falls I am recommending the adoption of a pressure of only 20,000 volts for transmission to Buffalo, and I am well aware that in doing so I am subjecting myself to the accusation of timidity in not wishing to go to a higher pressure. There is no question of timidity in this. I consider that for the 15 miles of distance which have to be traversed, the 20,000 volts giving, say, a loss on the line of only 3½ per cent. is amply sufficient; and it is more with a desire not to lead people to suppose that we are going to unusual pressures than for any other reason that I have not adopted a higher pressure. The manufacturing company which has had most experience in this direction proposed a pressure of 25,000 volts even for this short distance, and another electrician who has proposed using the continuous current in a manner, however, which would be quite unsuitable, has prepared his plans for a pressure of 20,000 volts, though every one with practical experience must admit that the danger in working a continuous current at this pressure would be very considerable.

It would have been possible for me to have gone considerably more into the details as to the methods which I would propose to adopt to make such a system as I have sketched out successful, but I feel that at the present stage of the enquiry what I have said is amply sufficient if the Committee will take it from me that I have naturally had occasion, in the course of my other professional work, to consider these details very thoroughly, and that generally the data from which I have worked out the cost above are such as would be conceded to be trustworthy by the engineering profession generally.

As to the uses to which such a supply of electricity could be devoted, this question will naturally come up for consideration by the Committee later. There is, first, the possibility of attracting large industries to places within 100 miles of the works. Again there is the electric lighting by both arc and incandescent lamps in Madras, Trichinopoly, Madura and elsewhere. There is also the field of electric traction, including, partly, tramways in the large towns, and longer tramways connecting outlying villages with towns. I have already alluded to the further possibility of working all the railways in the Presidency south of Madras by means of electricity, these being now worked by steam.

It seems quite clear that up to the distance of 350 miles, that is, up to Madras, it will be possible to supply electricity at any low pressure suitable for electric lighting or for motive power at a cost of not more than 4*l.* per horse-power per annum, including all costs with a margin for contingencies.

No. 5.

Report by Professor ROBERTS-AUSTEN, *C.B., F.R.S.* *Water-power at the Periyár Irrigation Works.*

Cost of Extraction of Aluminium.

The metallurgical questions which I have mainly to consider are those relating to the possibility of obtaining metallic aluminium by electrical energy, falling water being the motive power.

Mr. Chatterton's memorandum, which forms the basis of the inquiry entrusted to the Committee, states, page 3, that in the southern part of India there are numerous deposits of corundum which have long been worked as a source of emery. They occur in the districts of Salem, Coimbatore, Bellary, North Arcot and Kistna, in the Native State of Mysore and further off in Rewah and the Khasi Hills in Assam. I have consulted the authority * cited by Mr. Chatterton as describing the Indian deposits of corundum, but cannot find any analyses of the materials. I have analysed a specimen of corundum from the Salem district

* "Manual of the Geology of India," Part III; "Economic Geology," by V. Ball, London, Trubner & Co., 1881.

obtained from the Geological Museum of Jermyn Street, and find it to be of a high degree of purity, but I have no means of ascertaining whether it is an average sample. It is added that it is not absolutely certain that these deposits would be capable of yielding the 40,000 tons per annum which it is estimated will be required. It is also stated that 10*l*. per ton would probably be the maximum price to be paid for it.

I have as yet been unable to obtain either from Sir George Birdwood, or from the Imperial Institute, specimens of the particular deposit which would probably afford the source of aluminium; I am therefore in doubt as to the purity of the deposits generally, or as to the readiness with which the corundum could be reduced by electrical agency. I do not propose at present to give details as to the exact nature of the plant which is to be adopted, but it will probably closely resemble that adopted at the Patricroft works near Manchester, of which elaborate descriptions are available. Attention will therefore be mainly directed to the considerations of such details of cost of production as can be obtained.

First as regards the energy required for the electrical reduction of aluminium.

Mr. Chatterton's memorandum states that in 1890 at Pittsburgh, about 500 horse-power is continuously employed in the production of 375 lb. of aluminium per day. He also quotes from a paper published by Mr. J. H. J. Dagger * in which it is stated that an electrical furnace absorbing 500 horse-power, working Cowle's process, yielded 410 lb. of aluminium in the form of alloy. I am of opinion that the adoption of Cowle's original process, which only yields alloys of aluminium with copper or iron, should not be contemplated, and that it will be preferable to direct attention on the production of pure aluminium, and for this the prominent processes are those of Heroult, of Hall, and of Minet. The best known works for the production of aluminium itself is the "Aluminium Industrie-Actien-Gesellshaft, Neuhausen, at Schaffhausen on the Rhine." The dynamos are furnished by the firm of Escher, Wyss & Co., Oerlikon, near Zurich.

* Report, British Association, 1889, p. 538.

Three dynamos are employed, two of 600 horse-power and one of 300 horse-power. This is probably equivalent to 482 English horse-power and 241 English horse-power respectively. The axes of rotation are vertical.

Great care seems to be directed to the control of the speed of the turbines and dynamos which is known to be an important point in connection with all electrical installations devoted to metallurgical purposes. Each dynamo is of multipolar type, and gives a working current of about 6,000 to 7,000 amperes. The potential is about 30 volts with a speed of about 150 to 200 revolutions per minute.

At Froges, in the Department of Isere, France, the installation is similar in character, and the bath submitted to the action of the electric current consists of alumina diffused or melted in fused cryolite, the native double fluoride of aluminium and sodium. Without going into precise details it may be well to add that in both the Heroult and Hall processes, the bath is either bauxite or preferably pure alumina suspended in fused cryolite, a layer of copper or of iron being sometimes placed at the bottom of the bath when it is desired to form alloys with the liberated aluminium. In the Minet process, on the other hand, the bath which is submitted to the influence of the current contains 30 to 40 per cent. of an artificial fluoride of aluminium and sodium and 60 to 70 per cent of common salt, the bath being regenerated with pure alumina. The composition of the bath however varies, one proportion being—

1 part cryolite.
2 parts artificial fluoride.
4 ,, alumina.

The cost of horse-power at the Periyár works is estimated by Colonel Pennycuick at Rs. 20 per annum for 24 hours daily. At Pittsburgh it is found that 22 electrical horse-power hours (or 16,412 Watts) are required for the production of a pound of aluminium. Assuming that a loss of 15 per cent. occurs, and that 25·9 horse-power is required at the turbine to produce the 22 E horse-power at the bath, this on Colonel Pennycuick's estimate would cost 1·07 pence (valuing the rupee at $\frac{1}{16}$ of a sovereign).

With reference to this estimate it may be well to point out that Professor Coleman Sillers stated in 1891, with reference to the production of aluminium, that he did not consider it "safe to predicate the value of metal, produced upon anything short of $15 per horse-power per annum, for 24 hours daily, while perhaps $20 per horse-power would cover all contingencies." This would give for 22 electrical horse-power [allowing (as he did only) 10 per cent. loss in conversion], 6 cents, or 3 pence, as against Colonel Pennycuick's 1·42 pence.

A still more recent estimate by Herr Diebl puts the probable cost of energy in the Heroult and Minet processes respectively at a much higher figure as will be seen by the annexed table, yet his estimate for the total cost of a pound of aluminium by the Heroult process is under 2*s*. and for that produced by the Minet process a little over 1*s*.

It will thus be seen that the cost of energy as estimated by Colonel Pennycuick compares very favourably, even if the output of the proposed works should be forced to such an extent as to require a higher voltage.

If the voltage were raised to 20 at the bath, then 35 horse-power hours would be theoretically required to produce a pound of aluminium, and the cost of energy would be raised to 2·23 pence, but the establishment charges might in this way be somewhat reduced. It may be assumed that in a large work the cheapness of the Native labour would counterbalance the increased cost of superintendence, and the two items of cost—labour and superintendence—might be taken at $1\frac{1}{2}$*d.* per lb. of aluminium produced. In consideration of the fact that all appliances would need to be brought from a great distance, it would be well to allow 2*d.* per lb. to meet the charges of interest on capital and for repairs. Chemical stores would be also expensive, and 1*d.* per lb had better be allowed for this item; and as carbons suitable for electrolytic work at high temperatures have to be exceedingly dense, ordinary charcoal is quite unsuitable. As a safe approximation, based on such imperfect data as I have been able to collect, I should say that suitable electrodes could not be produced under a cost of 2*d.* a pound at the spot.

The estimate therefore will be—

	d.
Energy	1·10
Alumina, 2 lb.	6·0
Labour and superintendence	1·5
Interest, repairs, and maintenance	2·0
Chemical stores	1·0
Carbon electrode	2·0

	s. *d.*
Cost of 1 lb. ...	1 1 6

Captain Hunt's estimate of the cost of producing 1 lb. of aluminium—

	d.
2 lb. alumina (52·9 Al.)	3
1 lb. carbon electrode	1
Chemicals, carbon dust, pots	0·5
22 electrical horse-power hours (water-power)	2·5
Labour and superintendence	1·5
General expense, interest, and repair	1·5
Total cost ...	10·0

Very grave considerations are presented by the nature of the material it is proposed to employ.

Mr. Chatterton allows 1·1*d.* a pound for the cost of the corundum, or if alumina were imported from Germany he places the cost at 20*l.* per ton, or say, 2·2*d.* a pound, and such alumina would not contain more than 50 per cent. aluminium. I believe that this is considerably under-estimated; on the other hand an authority already quoted places the cost of prepared alumina (containing 52·9 per cent. of aluminium) at 1·5*d.* per lb. If the corundum is associated with either much iron or silica, its reduction will present great difficulties. It is not easy to purify aluminium from silicon and iron, and moreover the presence of much silica in the bath would lead to great loss, as it would decompose the cryolite giving rise to the evolution of fluorine. Much will, therefore, depend on the purity of the corundum and on the readiness with which it can be reduced. In the absence of direct experiment upon these points, I incline to the opinion that it will be preferable to employ artificially prepared alumina rather than the Native mineral.

Appendix to No. 5.

Zeitschrift des Vereines Deutscher Ingenieure Sieger District Meeting, 7th June 1892, 27th May 1893, p. 600.

Manufacture of Aluminium, Hr. Diell.

Method and raw material.	Cost of 100 lb.	Per cent of aluminium.	Cost of 1 lb. A l in raw material.	Rates for 1 lb. of aluminium yielded.		Horse-power hours for each 1 lb aluminium.		Value of horse-power hours in shilling, at 0·061 per horse-power hour.	
				60 per cent.	90 per cent.	60 per cent.	90 per cent.	60 per cent.	90 per cent.
1	2	3	4	5	6	7	8	9	10.
1. Cowle's, Alumina	27·7	50·0	·554	..	..	..	..	..	..
2. Heroult, do.	27·7	50·0	·554	14·545	..	19·5	..	1·189	..
3. Minet, Cryolite (with chloride of sodium) Alumina	4·536	84·0	·566	13·636	9·090	18·3	12·2	1·116	·744

Method and raw material.	Bye-products with 1 lb. aluminium.			Amount of		Value in shillings.	Total cost of production.	—
	Co.	Cl.	Value.	Carbon electrode.	Coke.			
	11	12	13	14	15	16	17	18
1. Cowle's, Alumina	1·52	..	..	..	..	..	..	..
2. Heroult do.	1·52	..	..	·60	..	·068	1·811	..
3. Minet, Cryolite (with chloride of sodium) Alumina .. .	..	3·87	·445	..	·20	·184	{ 1·361 { 1·049	for 60%. for 90%.

(Signed) J. HANNAN,
Ag. Joint Secy. to Government, P.W.D.

APPENDIX IV.

Extract from letter from the Sub-divisional Officer, Tirumangalam, to the Executive Engineer, Madura Division, dated 26th September 1897, No. 389 (with six samples of limestone).

* * * * *

2. *Sample No.* 1 is from Pandalgudi village, 8 miles due south of Aruppucottai in Ramnad zemindari. Nearest railway station in Tulukuppatti, distance 12 miles (no metalled road). Each local cart carries about 700 to 800 lb. of this stone. Cart-hire is Rs. 1½ ; cost of quarrying is 8 annas per cubic yard. This limestone is had 3 feet below ground surface and lies in blocks, large and small, varying in thickness from 4 to 9 feet.

Probable extent of bed is about 12 miles long and a furlong width.

Sample No. 2 is from dry lands near Virudupatti village, belonging to Tirumangalam taluk of Madura district. Virudupatti itself is a railway station. Each local cart carries 700 to 800 lb. of this stone. Hire is 2 annas per mile per cart, cost of quarrying is 8 annas per cubic yard. This limestone lies in blocks and almost on ground surface. Its thickness varies from 3 feet to 10 feet. Probable extent of bed is about 7 miles long and a furlong wide.

* * * * *

Sample No. 5.—This quarry is at Karumathur village in Tirumangalam taluk of Madura district. Nearest railway station is Sholavandan. Distance 10 miles (metalled road) and there being the Vaigai river to be crossed. Carts will generally go to Madura Railway station which is 14 miles from the quarry (metalled road). Each local cart carries 1,000 lb. and hire is Rs. 1¼ per cart. Cost of quarrying is 8 annas per cubic yard. This limestone is had in small nodular masses and the samples sent are the biggest size available. It is buried 3 feet below ground and is quarried to a depth of 9 feet. Probable extent of bed is about 3 miles long and a mile broad.

* * * * *

3. It may not be out of place to mention that for quarrying limestones from tracts belonging to zemindaris something will have to be paid in shape of seigniorage at 2 annas per cubic yard.

* * * * *

From Surgeon-Major J. L. VANGEYZEL, M.B., F.I.C., F.C.S., Chemical Examiner, to the Chief Engineer and Joint Secretary to Government, Public Works Department, Irrigation Branch, dated Madras, 11th November 1897, *No.* 1068.

With reference to your letter, No. 351 M., dated 20th October 1897, I have the honour to forward the results of the analyses of the samples of Madura stone and coral. It will be seen therefrom that the Madura stones I and II are almost pure calcium carbonate. The total amount of lime (CaO) present in each of these accounts in round figures for 99 per cent. of pure calcium carbonate in each of the stones. The total carbonic anhydride (Co_2) in each of these when converted into its equivalent of calcium carbonate works out at 97 and 98 per cent. of calcium carbonate, respectively.

The other stone and the corals are not so suitable for the purpose which you have in view.

ENCLOSURE.

ANALYSES of three samples of limestones and two samples of coral.

—		No. I stone from Pandalgudi.	No. II stone from Virudupatti.	No. V Karumathur limestone.	No. II coral.	No. III coral.
Moisture	.. P.C.	Trace.	Trace.	0·806	1·582	0·253
Sand, etc., insoluble in Hydro-chloric acid ..	.. ,,	0·230	0·330	13·250	1·920	0·670
Ferric oxide and alumina ($Fe_2O_3 \times Al_2O_3$) ..	.. ,,	0·500	0·200	2·300	0·600	0·200
Lime (CaO)	.. ,,	55·328	55·440	45·976	46·984	53·032
Magnesia (MgO)	.. ,,	0·072	0·216	0·432	0·252	0·144
Sulphuric anhydride (So_3)	.. ,,	Trace.	Trace.	0·085	0·532	0·480
Carbonic anhydride (Co_2)	.. ,,	43·000	43·200	35·600	38·800	39·600
Chlorine	.. ,,	Trace.	Trace.	0·022	0·621	0·035
Alkalies, phosphates, etc.	.. ,,	0·870	0·614	1·529	8·709	5·586
	Total ..	100·000	100·000	100·000	100·000	100·000

Confidential

REPORT

ON THE

UTILIZATION OF WATER POWER

AT

THE PERIYAR

FOR THE GENERATION AND TRANSMISSION OF ELECTRICAL ENERGY

BY

Major A. J deLOTBINIERE, R.E.

HIGGINBOTHAM AND CO., PRINTERS, MADRAS AND BANGALORE.

[illegible]

[illegible]

Through The Hon'ble the Resident in Mysore.

[illegible]

In accordance with the [illegible] letter No. [illegible] dated [illegible] from the [illegible] Secretary to the [illegible] I have the honour to submit the enclosed report on [illegible] of the water power from the [illegible] industrial purposes in Southern India.

[illegible] communities in Southern India.

[illegible]

[illegible]

I have the honour to be,

[illegible]

Your most obedient servant,

[illegible]

From

MAJOR A. J deLOTBINIERE, R.E.,

BANGALORE.

To

A. H. GARRETT, ESQ.,

Joint Secretary to Govt., Irrigation Branch,

P. W. D., MADRAS.

Through The Hon'ble. the Resident in Mysore.

June, 1904.

SIR,

In accordance with the request conveyed to me, in letter No. 109 C. dated 19th May 1904, from the First Assistant to the Hon'ble. the Resident in Mysore, I have the honor to submit the enclosed report on the utilization of the water power from the Periyar Irrigation Works, for Industrial purposes in Southern India.

I beg to thank His Excellency the Governor in Council, for what I consider the exceptional opportunity now given me in assisting the Madras Government, if even in the smallest manner, to bring this great national asset (cheap power) into circulation, amongst the Agricultural and the Industrial Communities in Southern India.

What I have written and suggested in my Report, is based on actual experience, and I hopefully trust that if the project is carried out, the forecasts given, will, both financially and mechanically, be fully realized.

I would strongly urge that you represent, the desirability of Government undertaking the first Installation of Power. After this has been done, and the general public have had an opportunity to realize the benefits to be derived from cheap power, I venture to predict that there will be no lack of applicants for the remaining water rights at the Periyar.

I have the honor to be,

Sir,

Your most obedient servant,

A. J deLOTBINIERE, MAJOR, R.E.

REPORT ON THE UTILIZATION OF WATER POWER AT THE PERIYAR.

I propose to divide this report into four sections, following the natural channels of thought, when considering an undertaking of this nature.

The first section, is a reply to the question immediately asked by all practical men.

Question A.

"Is the scheme practicable, if so, at what distance from the source can we deliver the power, at such a cheap rate that it will benefit consumers to adopt it, in preference to steam."

To enable me to reply to this question, I must first fully work out a complete project, and show exactly at what cost the power can be delivered at certain distances.

This section therefore is a reply to question A.

Question B.

Section two is a reply to the question "Does a market for the power exist, and are users prepared to adopt the power at the minimum rate at which we can deliver it."

Question C.

Having decided that the scheme is feasible, and financially sound, and that a market exists for the power, how are you going to set about the undertaking.

In Section three I give my views in detail on this point.

Section four treats generally on some of the duties on which cheap electrical power may be commercially employed in India, and endeavours to explain to what stage progress in that line has reached.

[illegible] ON THE UTILISATION OF WATER POWER AT THE [illegible]

Section 1.

PROPOSALS FOR PLANT AND DETAILS OF COST, ETC.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Section 1.

PROPOSALS FOR PLANT AND DETAILS OF COST, Etc.

Before going into this subject I would remark that I have carefully gone over the report of the Committee of 1893, composed of Col. Pennycuick R. E., and Professors George Forbes, Unwin, and Roberts-Austin. I regret to say that my experience in India, prohibits my agreeing with these gentlemen in their estimates, as to the matter of cost, erection of plant, and price at which it can be delivered to consumers.

The price quoted by Professor Forbes *i.e.*, £4 per H. P., per annum delivered in Madras, would in my opinion little more than pay for up-keep and maintenance of the plant, when it is remembered there is a transmission line of 340 miles long, to be looked after.

Colonel Pennycuick, and the members of the Committee, place the cost of one H. P. per annum in Madras, allowing that 1,000 H. P. are delivered for 10 hours a day during 300 days in the year, at Rs. 43 or less than £3, at Trichinopoly they give the cost under the same conditions at £2, and at Madura £1-12-0.

I will simply remark that my experience on the Cauvery Plant after two years' working, satisfies me that the annual cost of Maintenance alone, per H. P. for a plant of say 10,000 H. P. would probably be not less than £2 per H. P. and this is considerably below what I am paying at the present moment for 5,000 H. P.

This annual charge of £2 per H. P. simply covers, staff, oil, and small stores, and does not allow one rupee for depreciation and large repairs.

Under the circumstances, the figures given by the 1893 Committee, are I consider, somewhat misleading, when it is remembered that their figures are supposed to include 10 per. cent depreciation on portions of the plant, repairs, maintenance and profit on capital outlay.

I would also remark that in my opinion the cost of the plant given in the report, is on a par with the cost at which the Committee proposed selling the power.

The Committee place the cost of plant and line of conductors per horse power :—

at Madras (340 miles of line) ... ... at £ 39/- per H. P.

at Trichinopoly (128 miles of line) ... at £ 27/- per H. P.

at Madura (64 miles of line) ... ... at £ 21/- per H. P.

I would remark that the cost of the Cauvery Power per H. P. delivered on the Kolar Gold Fields 93 miles from the Generating Station, not allowing for the Anikat across the Cauvery, and Channels, works out to £45 or nearly twice the cost allowed by the members of the Committee, for power delivered at an equal distance.

In installing the Cauvery Plant, the proportion of Indian to Foreign expenditure was about equal, taking into account the Anikat and Channels but these were costly items. Whereas the Committee of 1893 apparently failed to realize the heavy cost of necessary works in India, which accounts for it so seriously under-estimating the cost of carrying out the Installation.

I have made the foregoing remarks simply to prepare Government for the figure which I give later on, and which after the 1893 Report will appear excessive, but I do not think I have over estimated in any particular.

Presuming that Government itself will carry out the first installation, which appears to me the only feasible way of developing the power, I propose to work out the cost of installing 10,000 H. P. with the necessary "Spares" and the cost of delivering this amount, 5,000 H. P. at Madura, and 5,000 H.P. at Trichinopoly.

I shall give an approximate figure for delivering 10,000 H. P, at Madras.

The final success of a plant both commercially and mechanically, can be ensured in a large measure by careful preliminary arrangements, and without going into great detail I propose giving my views as to what these preliminary steps should be.

1st. Government must know to within a narrow margin, what the actual cost of delivering the power at any given point will be.

2nd. A market for the power, at the rates shown to be necessary, must be obtained, these rates should be sufficient to cover interest on capital, repairs, cost of maintenance, and depreciation of plant.

3rd. The question as to how the work should be executed *i.e.* what contractors will be invited to compete, the scope of each one's work, and the portions of the work to be carried out by Government agency, must all be decided.

Taking these questions in their proper sequence :—

1st. What will it cost to deliver one H. P. unit at Madura, and Trichinopoly, taking 5,000 H. P. as the standard.

The data I have at my command is "Head" available 1,020 feet, minimum discharge at tunnel 500 cu-secs, slope of hill 1 in 3.

The first question to be settled is, in what size units will the plant be installed. Naturally the reply to this is, the larger the better. In Canada the New Niagara Falls Coy: are putting in units of 10,000 K. W.=over 13,000 H. P. each, this is done to cheapen the cost, but at the Periyar we are thousands of miles away from the factory, and the plant has to be carried in various ways, finally on trollies over country roads. Under the circumstances I cannot recommend units of more than 2000 K. W.=2666 H. P.

At the Cauvery Falls, our units are of 1000 H. P. each, but the difficulty of installation was great, as everything had to be lowered down a steep hill, whereas at the Periyar our Station would be on comparatively level ground at the foot of the hill.

Having settled on the size of each unit, the next question is how shall we use the fall, will it be broken into stages as proposed by the Committee of 1893, or used directly.

Although Professor Unwin recomends two stages, because of the saving in cost of penstocks, I do not hesitate a moment in strongly recommending that the full head be used direct.

After going carefully into this question, I find that taking into consideration the cost of two complete Generating Stations, if two stages be used, the extra cost entailed in the thicker steel in penstocks, if only one stage is used, is balanced, and that there is little to choose in first cost.

Where the great saving comes in however, is in the recurring cost of Establishment, and Maintenance charges. If we have two Generating Stations we must have two complete sets of operators, cleaners, oilers etc.

Each set consists of 3 complete watches, the plant must run the full 24 hours, and in India I find 8 hours out of 24 in a Generating Station, is a ful day's work for an operator.

Roughly speaking each watch will consist of the following :—

		Monthly wages.
1. Electrical Operator	Rs.	200
1. Assistant Electrical Operator ...	,,	125
1. Hydraulic Operator	,,	125
1. Assistant Hydraulic Operator ...	,,	75
4. Oilers @ Rs. 15 each	,,	60
2. Sweepers @ Rs. 12 each	,,	24
Total for one watch	Rs.	609

Say rupees six hundred Rs. 600.

For one Station, 3 watches will cost Rs. 600×3 = Rs. 1800 per month.

If we divide the fall we shall just double this establishment, which will mean nearly £1500 per annum extra.

Apart from this we must always have spare men for both Stations, and there is also the cost of quarters for all these extra people.

There is also the repairs and maintenance to the double set of plant and buildings, and also extra oil, waste, spares, and stores to be kept up for the second Station, which will easily come to £1,000 per annum.

In America a head of 1900 feet direct has been used for the last two years, for the generation of power, with excellent results.

I may mention that,

at Redlands, California, head used direct is	...1900 feet
at Fresno, California, ,, ,, ,, ,, ...	...1410 ,,
at Pikes Peak, Colorado, ,, ,, ,, ,, ...	...1150 ,,
at Sylvania, Ohio, ,, ,, ,, ,, ,, ...	...1000 ,,

These are only a few cases. Why should we, with this example before us, hesitate an instant to adopt what may now be called a medium high fall of 1,020 ft.

Regarding the size and thickness of penstocks, and number :—

From what I have seen in many parts of the world and from my own experience at the Cauvery, I strongly advocate a separate penstock for each wheel.

My reasons are :—

1st. The cost of separate piping for each wheel is little, if anything, more than when using one penstock for two or more wheels.

2nd. If anything should go wrong with the penstock, only one unit is shut down, which is a great consideration.

3rd. There is a great saving in the labor of laying the smaller pipes, and also in the item of carriage, which, in my opinion, carries great weight.

I therefore propose adopting a separate penstock for each unit.

We now come to the question of type of wheel and governor to be adopted. The 1893 Committee for various reasons, recommend a turbine in preference to a Pelton or Impulse wheel. Since 1893 things have changed, and to-day there can be no question as to a turbine *Versus* an Impulse wheel, for a head of 1020 feet.

To my knowledge every recently erected electrical installation, worked by water power with a head of 300 feet or over, is equipped with Impulse wheels or Peltons (practically the same thing).

These wheels all work on a horizontal shaft most satisfactorily. The 1893 Committee appeared to consider it fatal to success to adopt any hydraulic motor working on a horizontal shaft. This shows what an advance has been made in recent years.

The question of governing the wheels is a most important one, but when it is not a question of saving or impounding the water, the accurate governing of impulse wheels has been most satisfactorily solved.

The best method is to use a deflecting nozzle, worked by the Lombard Governor. This nozzle is simply depressed and the jet deflected from the wheel blades when the speed is too high, as the speed falls the nozzle is again raised into place automatically by the governor. This method gives most excellent results, the only drawback being that whether the plant is working at full or half load, the same quantity is used, but when the average load is known, the orifice of the nozzles can be adjusted to exactly supply sufficient water for the full load.

In the case of he t Periyar however, this method does not enter seriously into our calculations, as the water is primarily required for irrigation and must pass on. Another great function of the deflecting nozzle is, to protect the penstocks from shock, or ram, when the load is suddenly thrown off the plant.

In the ordinary type of governor, if the load is suddenly thrown off, say from full to half, the duty of the governor is to instantaneously shut off such a quantity of water, that the wheel will not accelerate its speed. To do this, (*i.e.*, shut off the water instantaneously) is liable to cause a heavy shock to the pipes, due to the column of water in the penstocks being suddenly checked, and with a head of 1,000 feet the blow given by the suddenly arrested column of water, is liable to burst the pipes. In all systems, unless deflecting nozzles are used, automatic relief must be provided in the system to minimize this shock, but nothing can be better than the deflecting nozzle, which in no way interrupts the steady and uniform flow of the water, whereas all automatic reliefs are liable to cause trouble, by failing to act at the proper moment.

I therefore strongly recommend the adoption of the deflecting nozzle, and Lombard Governor, in connection with it.

Lastly I must refer to the power of the wheels. For a generator to deliver 2,666 H. P., we require a wheel capable of delivering when called upon to do so, at least 30 per cent. more power than the rated out-put of the generator, this proviso is very important for many reasons.

I therefore strongly recommend that the wheels should be ordered with a guaranteed maximum capacity, of at least 3,500 H. P.

I shall now recapitulate my recommendations re the Hydraulic Plant.

i. That the full fall should be used direct, in one stage.

ii. That there should be a separate pipe or penstock, for each wheel.

iii. That the electrical units should be of 2,000 K. W., and the wheels equal to delivering 3,500 H. P.

iv. That the wheels should be of the Pelton, or Impulse type.

v. That the governing should be effected by means of deflecting nozzles, and Lombard Governors.

As regards the Electrical Plant, it would make this report too technical if I were to fully discuss the "pros" and "cons" of every electrical detail, and it would be a waste of time, as the details will depend in a large measure on which Company is selected to supply the plant. From experience I find that such companies as the Westinghouse, General Electric Company of New York, British Thompson Houston, and Oerlikon, all build standard plant, and do not care to undertake a large work of this kind, unless they are permitted to use their standard apparatus. Special conditions run the prices up by about 50 per cent, and are never so satisfactory as when standard machines are used.

Also if the contractors have to give guarantees, they do not care to risk their reputation in a work of this nature, unless their own views are adopted to a great extent.

I consider this stand on the part of a large Company with unique experience is perfectly justifiable, and I would always be prepared to accept the decision arrived at by such a Company as to details, as long as that Company gave me ample guarantees regarding the successful working of it's plant.

I should actually hesitate to employ a Company, which had no standard types or ideas of its own in the electrical line, and which was quite prepared to build and guarantee plant according to an outsider's ideas, simply in order to secure the contract.

Under the circumstances I will not go deeply into the question of details, as it would be quite useless, but I consider that for a successful plant, we should insist on three phase, alternating current, at a voltage of from 60,000 to 80,000 volts, with a periodicity or frequency, of from 30 to 60 cycles, this latter point naturally will depend on the nature of the load.

It is needless for me to explain at length why I have recommended the above, as in the case of the electrical portion of the scheme, I am quite in accord with the 1893 Committee, and my reasons for making the above proposals are clearly explained in that Committee's report.

I would suggest, oil insulated water cooled transformers, in fact it is essential that these should be used for voltages above 35,000.

Also that the Excitors should be independent of the Generators. Presumably the current will be generated at from 2,000 to 3,000 volts, and stepped up by the oil insulated water cooled transformers, to the line voltage of from 60,000 to 80,000 volts.

The question of voltage is one of the most important in the whole undertaking, as on this depends the amount of copper in the line. I may state that to double the voltage, means to divide the weight of copper in the line used to transmit a given power to a given distance, by four. Under the circumstances our natural aim is to raise the voltage, and save copper.

When the time comes, the question for the big electrical firms to decide will be, what voltage they are prepared to guarantee the transformers and insulators, to stand? To-day voltages of 60,000 are used commercially. I would be prepared to use anything up to 80,000 in the Periyar Scheme, if guarantees were satisfactory, but for purposes of calculating the necessary copper, I will adopt 60,000 volts as our standard, with a line loss of from 15 to 20 per cent.

Regarding the line loss, this is also an important factor, as the less power we lose on the line in transmission, the greater weight of conductor is necessary to carry a given power.

Naturally the more power lost on the line, the greater power needed in the generating station, and the poorer the regulation of the system. Under the circumstances there is a limit to the loss we can permit on the line. Taking all things into consideration, regulation of consumers' motors, extra generator power required etc., I recommend that the line loss should in no case be more than 20 per cent.

I shall now take up the questions of spare, or reserve power. In the case of an installation capable of delivering 10,000 H. P., with a loss of 15 per cent in the line, the various electrical losses to be provided for in order to actually deliver 10,000 H. P., to consumers, may be stated as below.

Approximate additional electrical power to be added in Generating Station, above that required at receiving end, to cover electrical losses in the system.

Efficiency of	Step up Transformers ...	·975	per cent.
Do	Line	·85	,,
Do	Step down Transformers ...	·975	,,
Do	Secondary Distribution ..	·95	,,

This works out to 25 per cent.

Then for 10,000 H. P. delivered, we require capacity in Generating Station of 12,250 H. P.

We would therefore require to instal ¼ more power in Generators and Transformers, than we desire to deliver.

Ten thousand horse power are equal to 7,460 K. W., we have therefore to instal 9,325 K. W., to meet a demand of 10,000 H. P. half at Madura, and half at Trichinopoly.

This means that 5 units of 2,000 K. W. are ample for our requirements.

I would add one extra unit as a reserve, this will it is thought, be found quite sufficient.

Our installation therefore, would consist of 6 units of 2,000 K. W. each=16,085 H. P.

Regarding Exciters, we should require two, each of about 240 K. W. each Exciter to be capable of serving the whole 6 Generators, and to provide power for lighting, fans, etc.

As regards Transformers, as previouly pointed out, we have no choice in the matter, these must be of the oil insulated, water cooled type.

I would propose having these in groups of three, one for each phase, of a capacity of 750 K. W. each.

The same proportion of spares will be provided, as in the case of the Generating Plant.

Regarding Transmission line, I consider for any distance over 100 miles, and in fact in any case to ensure continuity of power, this must be in duplicate.

I do not propose to provide two lines, with copper in each capable of doing the whole work, what I propose is two lines, each capable of carrying say 60 per cent. of the normal load, at 15 per cent. loss.

Section Stations will be provided every 30 miles or more, which will permit of any section of either line being cut out for repairs, without interfering with the rest of the line.

For instance say we have two lines A and B, and these lines are divided into 3 sections, which we call 1, 2, and 3. A report comes in, that an insulator has failed on section 2 of line A.

In that case the section is cut out by means of switches at the Section Stations, and the whole current for that section is carried on section 2, line B, which section will for a time carry double load, but sections 1 and 3 of both lines A and B, continue to do normal work.

Or it may happen that there are faults at the same time on section 1 of the line A and section 3 of the line B, in this case both sections are cut out, and the whole current is carried on section 1 of the line B, sections 2 of both lines A and B, and section 3 of line A. This may be done by a proportionate increase of voltage at the Generating Station.

That is to say for one fault we only cut out 1/6th of our copper, and use the other 5/6ths, and so on.

I have no hesitation in stating, that two such lines sub-divided as proposed, will be found in practice, more reliable in maintaining continuous service than two, and probably quite equal to three through lines, each of full capacity. In the case of a through line, one faulty insulator or other defect, necessitates the whole of the line being thrown out of service, until the defect has been discovered and remedied, whereas the section system greatly facilitates the localization of faults, and consequently their prompt rectification.

I strongly recommend the use of Section Stations equipped with approved lightning arresters, on all long transmission lines.

The question of insulators is also a most important one, but without going deeply into this, I consider that such rapid strides are being made in this direction that manufacturers of to-day, would be prepared to supply an insulator capable of carrying 100,000 volts.

I may mention that sea fog is the worst enemy to high voltage transmission. In India we happily are spared this, and generally our climait conditions are good for long distance transmission.

The line is naturally the most vulnerable part of a power transmission plant, and under the circumstances too much care and thought cannot be given to every detail in its construction.

I would propose iron poles, and iron or wooden cross arms, these latter enable leakage to be detected at a glance, as the arms char when a considerable current passes over them, due to leakage from an insulator.

The question of ordinary poles placed at 130 feet interval, or light iron lattice work pillars, spaced at intervals of between 400 and 500 feet, deserves consideration, and doubtless will receive it when final details are decided upon.

Finally if the line is thoroughly well built, and a proper number of Section Stations provided, I have no hesitation in saying that power can be carried continuously day and night, for 365 days in the year, to any point situated within a commercial radius of the Generating Station, and this commercial radius depends primarily on the price of coal, and the cost of electrical power delivered.

That is to say, we can deliver power continuously at any point at which we can sell it at a profit.

Having explained my views, and decided on the leading features of the Installation, I shall now give a detailed estimate of the probable cost of carrying out the proposals made.

This estimate will include, cost of plant at factory, packing, insurance, sea freightage, landing charges, railage, road carriage to site, and erection, also the cost of necessary buildings in which the plant will be installed, with all subsidiary items such as Staff Quarters, Workshop, Stores, etc.

Estimate of Probable Cost.

Estimate of the probable cost of supplying, and completely installing, an Hydraulic, Electrical Power Transmission Plant, capable of delivering 5000 H. P. at Madura, and 5000 H. P. at Trichinopoly, 64 and 128 miles respectively, from the Generating Station.

HEADS OF WORK.	COST. Of each.	Total.
	£.	£.
PLANT. **I. Hydraulic Plant.**		
6 Penstocks (steel rivetted) each 3000′ long, with expansion joints, thrust-blocks, valves, and all accessories complete. Each penstock to be of 33″ mean diameter, and of ·47 mean thickness. ...		
Each penstock can supply 15,400 Gals. per minute, with a mean velocity of 7·07 ft per second, the total loss of head due to friction being about 20′.		
This is sufficient to generate over 3,600 H.P., taking the efficiency of the water wheels at ·75. This is however low for wheels of the Pelton type, from which an efficiency of ·80, may confidently be anticipated ...		
Each penstock of given dimensions will weigh approxty: 300 tons, including special pieces		
Total weight will thus be 1,800 tons, and cost F. O. B. England, allowing for specials etc., will be approximately ...	33,000	
6 Water-wheels with Lombard Governors, deflecting nozzles, and all fittings complete. Each wheel capable of developing 3,500 H.P. Cost F. O. B. Europe or America, at £3,500 each	21,000	
2 Exciter wheels, of 350 H. P. each, complete in all respects as for main wheels. Cost at £350 each	700	
Special piping within the power House, with valves etc: also spare parts for water-wheels	1,000	
		55,700
Total cost of Hydraulic Plant, capable of generating 21,000 H. P. (F.O.B.) ...		£55,700

HEADS OF WORK	Cost. Of each.	Cost. Total.
	£.	£.
II.—Electrical Plant		
(*a*) *At Generating Station.*		
6 Alternating 2,000 K. W. Generators, 3 phase, revolving field, 24 poles, speed 300 revolutions. Voltage anything from 2,200 at full load, to 4,000. Excited by continuous current at 125 Volts. Price (F. O. B.) £5,400 each	32,400	
2 Direct current, 8 pole, 250 K. W. 125 volts exciters, compound wound, to run at 200 revolutions	2,000	
Price with equalizing connection complete. (F. O. B.) £1,000 each	10,800	
18-700 K. W. oil insulated, water cooled Transformers, for raising voltage to 60,000, each £600 (F. O. B.)	720	
6 Marble panels for Generators, complete with all necessary instruments, switches etc; etc; Price £120 each (F. O. B.) ...	2,500	
High tension bus arrangement, complete with switches etc; Cost. (F. O. B.) ...	1,700	
Panels for Exciters, Lighting, Transformers (low tension) Control, Totalizing, Local Circuits, and regulators complete ...	200	
High tension Lightning Arrestors for Station, complete	2,500	52,820
Spare parts, and small fittings etc; for Generating Station		
Total cost of Electrical Plant at Generating Station, (capacity 16,000 H. P.) ...		£ 52,820

HEADS OF WORK.	Cost. Of each.	Cost. Total.
	£.	£.
Electrical Plant.		
(b) *Transmission.*		
Transmission Line (double pole line with one circuit on each) to carry 5,000 H.P. to Madura, and 5,000 H. P on to Trichinopoly.		
Station voltage to be 60,000		
Receiving voltage at Madura, 53,000 ...		
Do do at Trichinopoly, 50,000 ..		
Line loss 12 per cent at Madura, and 18 per cent at Trichinopoly.		
Total copper required in lines, 375 tons, approxty: at £60 per ton	22,500	
10,240 Iron poles for two lines, at 40 poles per mile, (128 × 40 × 2) at £2 per pole	20,480	
40,000 High tension insulators and pins, (allowing 3 per pole and spares) at 6/6 each	13,000	
10,240 Cross arms, with bolts and braces complete, at 4/- each	2,048	
Apparatus for four Section Stations complete, at £1,000 each	4,000	
Step-down Transformers, Panels, Lightning Arresters, and all requisite electrical apparatus, with fittings complete, for Transformer Stations at Madura and Trichinopoly		
Two sets complete, at £9,000 each	18,000	
		80,028
Total cost of Plant for Transmission Lines to Madura and Trichinopoly, including 4 Section Stations, and 2 Step-down Transformer Stations.	...	80,028

HEADS OF WORK.	COST. Of each.	COST. Total.
	£.	£.
Recapitulation of cost of Hydraulic, and Electrical Plant, (F. O. B.)		
Hydraulic Plant	55,700	
Generation	52,800	
Electrical Plant.		
Transmission	80,028	
		188,548
For Sea freight, carriage by rail and road, erection (including cost of Staff, and Tools and Plant) also Insurance charges, add 40 per cent. of total cost of the Plant (F.O.B.)		75,419
Grand total cost of Plant, erected complete...		263,967

PROBABLE COST OF WORKS IN INDIA.

	£.	£.
Preliminary expenses in connection with the preparation of the project, survey charges, etc ; etc;	5,000	
Fore-bay, and Head Works	7,000	
Preparing hill-side for Penstocks	3,000	
Generating and Transformer station, in one...	21,000	
Section Stations (4) on Transmission Line ...	4,000	
Transformer Station (Step-down) one at Madura, and one at Trichinopoly ...	5,000	
Quarters for staff at Head Works, Workshop, Hospital, Recreation Rooms, Water Supply, and all subsidiary buildings, complete	15,000	
Quarters, and Rest House on T. Line ...	4,000	
Carriage of polse and other line material, with erection complete	7,000	
Acquisition of land, and track along Transmission Line	7,000	
Roads, bridges, and drains etc ; Head Works	4,000	
		82,000
Grand total estimated cost of Works in India		82,000

£

Plant &c 500 000

Reservoir &c ~~400000~~

~~600000~~

900000

Revenue

30000 HP at £5) 150.000

Deduct

Annual working exp 60000

Depreciation Plant 25000

85 000

85000

~~40000~~

65 000

10

£4 on £60

60 100

~~100~~ : ~~60~~ :: 4 : x

$x = \frac{240}{100}$

$x = \frac{400}{60}$

£

Cost of entire scheme 900000

Revenue

30000 H P at
Rs 5/- per H = 150000

Annual working
expenses 60000

Depreciation of
plant 25000

85000 85-000

65000

Rent from 25000 acres of land
at Rs 4 = 1 lakh
or £ 6000

Lower reservoir	47,40,900
Kurmile Cut & Regulator	3,95,400
Diversion of [illegible] road	2,00,000
	53,36,300

15) 53 36 300 (355 75
45
83
75
86
75
113
105
80

15) 60 00000
400000

	£.
Total estimated cost of Plant, including erection	263,967
Total estimated cost of Works in India	82,000
Total	£345,967
Add contingencies at 5 per cent.	17,398
Grand total estimated cost of the Scheme....	**£363,265**

This equals £36 per H. P. delivered, half at Madura, and half at Trichinopoly.

The actual cost of installing the Plant, to deliver 5,000 H. P. at Madura, and 5,000 H. P. at Trichinopoly, works out to about £33, and £40 per H. P. respectively.

NOTE.—The cost of a telephone service, a most essential feature in a scheme of this kind, has not been included in the foregoing estimate, as it is thought that this could probably be arranged for, through the Government of India Telegraph Department.

With regard to the Distribution of the Power, Consumers would of course be required to instal their own motors etc.; and the point of delivery would be the "Buss-bars" in the Step-down Transformer Stations. The question regarding the incidence of cost of the Distribution linework, within town limits, is left open for subsequent settlement by the authorities concerned.

I may mention that in getting out the detailed prices for the Electrical plant I have received valuable assistance from Mr. H. P. Gibbs, Chief Electrical Engineer to the Mysore Government.

ANNUAL MAINTENANCE & WORKING EXPENSES Etc.

Two pounds sterling per H. P. is considered a safe estimate to meet the cost of establishment, renewals, repairs to Plant and Buildings, lubricants, and small stores. This sum should keep the whole system in first class order.

	£.
Annual working expenses, (10,000 x 2)	20,000
Depreciation of Plant, 5 per cent on estimated cost (264,000)	13,200
Interest on the total Capital invested, at 5 per cent, *i.e.*, 5 per cent on £ 363,000	18,150
Total estimated cost per annum, of 10,000 H. P. delivered	£51,350

or, £ 5-2-8 per H. P.

The power could therefore be sold, to yield a clear profit of 5 per cent, at the following rates.

At Madura, £ 4-15-0 per H. P.

At Trichinopoly, 5- 7-0 ,,

It should be pointed out however, that these are "Flat rates," *i.e.*, the rates at which one H. P. would be sold for full time (day and night) for 365 days in the year.

In the event of Consumers preferring a meter rate, the prices would have to be raised sufficiently to ensure the above return, even though the power were generally used for but ten hours daily, and on about 300 days only in the year.

The "Flat rate" is therefore recommended for adoption.

At Madras the cost of a Horse power delivered, should not exceed £65, and the selling rate for one horse power day and night, for 365 days in the year, on the same conditions as for Madura and Trichinopoly, may be put at £7-10-0 approximately.

It must be remembered however, that this figure is based upon the assumption, that a line voltage of 80,000 will be found practicable.

Note.—Since working out the above details of cost, I have been informed by the Chief Engineer for Irrigation that it will be necessary in the interests of cultivation, to construct new, or enlarge existing tanks, in the valley below the Generating Station, to impound the water used for power purposes during the months of March, April, and May of each year.

The cost of these works will naturally depend on the amount of power generated, and may be roughly put at Rs. 1,00,000 per 1,000 H. P. Therefore if we eventually generate 40,000 H. P., we must spend 40 lakhs of rupees on these tanks, which at 5 per cent. interest, will add £14,000 to our annual charges, or an addition of 12 shillings per H. P. per annum, to the selling price.

But as these tanks may be useful in other ways, it may be possible to charge off part of the interest on the capital spent in their construction to other heads, or the increased irrigation revenue derived from the existence of these tanks, may be sufficient to fully meet the interest on capital outlay.

Section. 2.

MARKET FOR THE PERIYAR POWER.

In order to obtain an idea of the light in which consumers in Southern India, would regard the advent of cheap electrical power, I sent a circular letter (Appendix A) to all those who I thought might be interested in the matter.

Replies to this circular came in very slowly. I therefore thought it advisable to make a short tour through the principal centres of industry, to personally discuss the question with those directly interested.

At Trichinopoly I found the Municipality was anxious to adopt electrical power if available, for all undertakings controlled by it, which in this case comprise pumping, a light railway, and electric lighting.

The management of the S. I. Ry. also went with me as far as possible, into the question of the electrification of a section of the S. I. Ry. The section taken for discussion, comprised the main line between Trichinopoly and Tuticorin. By going into the question of Horse Power necessary at any one moment, to propel the trains on the line running in both directions between these points, it was found that 2,500 H. P. would meet all requirements. This figure of 2,500 H. P. represents the maximum power which would be required at any one instant. It therefore fixes the minimum energy which the Periyar Power authorities would be obliged to keep on the railway conductors throughout the 24 hours. The advantages accruing to the railway through having this large block of energy available throughout the 24 hours, are very marked. For instance it will enable the railway to run the maximum number of trains throughout the 24 hours, without entailing any extra cost for power, as in any case the maximum power must necessarily be maintained constantly on the lines, and paid for whether used or not.

I suggested that it might be possible to sell this power at £ 9 per H. P. per annum (day and night for 24 hours) and at that price it appears that the railway would profit considerably, by the use of the Periyar Power.

Naturally the question being of such a large and technical nature, nothing definite could be arrived at, but as far as the management in India is concerned, the question of the electrification of the S. I. Ry. would appear to have its full sympathy and support. For information as to the progress which may be expected, in the electrification of main lines of railways within the next year or two, please see page 26 of section 4 of this report.

From Trichinopoly I proceeded to Madura.

The question of the use of the Periyar Power at this place, appears to appeal strongly to those concerned. The Chairman of the Municipality (Mr. Reilly) looked forward with pleasure to the advent of the power, which he proposed using for running the water supply pumps, the "Shone system" of drainage, shortly to be introduced, a light tramway for the removal of rubbish outside the city limits, and for electric lighting of the City.

These services would call for approximately 1,000 H. P. day and night, and the rate at which I offered the power, viz., £ 6 per annum, would show a gain over steam power used day and night, of from 50 to 65 per cent.

The manager of Messrs Harvey & Co's large cotton mill at Madura, (Mr. Clarke) readily met the suggestion to substitute electrical power for driving his mill, in place of steam, and assured me that as far as he was concerned he was strongly in favour of the change, and that the matter would be immediately put before his managers.

The rate I offered him, £5 per H. P. day and night, per annum, appears low enough to fully warrant in his opinion, the change from steam.

This mill would require 1,000 H. P. to commence with.

Madura therefore offers, an immediate market for 2,000 H. P. and of course when once power reaches this large city, there will be many more calls from all quarters.

I should not be surprised, if the demand in Madura and its vicinity alone, should reach 5,000 H. P within a year of the introduction of Periyar Power, if Government can deliver it, at say an average of about £ 4-10-0, per H. P. per annum.

I next visited Tuticorin where there is a very large cotton mill, (the Coral Mill) using 1250 H. P. and a large number of cotton presses. The acting manager of this mill, could not be brought to understand or appreciate what I was offering him, and as far as I could see, would not recommend the use of electrical power to his directors at any price, but of course this attitude on the part of a manager carries no real weight, and I anticipate that before the carrying out of the first installation of the Periyar Power is completed, the whole of the Tuticorin mills will have made offers for the power. All the cotton press managers were ready to become customers.

I therefore consider Tuticorin will take 2,000 H. P. at least, to commence with.

Generally speaking I consider there will be a good market for Periyar Power in Southern India, from the first.

Coming to the question of the utilization of the power in the immediate vicinity of the Generating Station :—

It would appear that the large tea estates within 30 miles of the Power Station will be ready consumers, and I consider Government might sell to these estates, at from £ 2-15-0, to £ 3-10-0 per H. P. per annum, day and night. This influx of cheap power into the tea districts, will prove a great boon to the planting community, and will probably lead to developments in directions little thought of to day.

Both sides of the Kumbam valley, through which the Periyar water flows, may readily be brought under wet cultivation by pumping. This duty alone, would employ a large portion of the available power from the first installation.

The proposed railway from Ammayanayakanur to Kuruvanthi, at the foot of the hills near the Generating Station, which I understand will be put in hand within a few months, will naturally be worked by Periyar Power.

When this railway is completed, what an opportunity will be opened to manufacturers to carry on industries in the valley along the railway line, where Government could give power at a practically nominal rate, of say from £ 2 to £ 3 per H. P. !

I may mention that I sent several copies of circular letter No. 1 (Appendix A) to the Secretary, Bombay Mill Owners' Association, with a

suggestion that the Bombay Mill Owners, might consider the establishment of branch mills near the site of the Power Station, where energy could be supplied at a very low cost.

I received an encouraging reply from Bombay, to this suggestion.

However it now appears to me, that before offering advantages to the Bombay Mill Owners, those of Southern India should first be given an opportunity to accept our cheap power.

With a railway running close up to the Generating Station, it appears to me that Government will be in a position to offer terms, even more favourable, than those offered by the Niagara Power Company.

At Niagara, electrical power competes against good coal at from Rs. 7 to Rs. 8. per ton. At the Periyar, we compete against indifferent Indian coal, at a price of from Rs. 12 to Rs. 16, per ton. In America, manufacturers found it well worth their while, to open factories in the immediate vicinity of the Power Station. Surely the industrial world in India, with more to gain than in the case of America, cannot hesitate long in taking advantage of such an opportunity.

To come down to figures, without a long transmission line to construct and maintain, and selling power in large blocks, say of from 500 to 1000 H. P., I consider Government can safely offer power, say for a distance of 10 miles from the Generating Station, at from £1-10-0, to £2-10 0, per H. P. per annum, day and night. Taking the mean, say we offer power at £ 2 or Rs. 30 per H. P. per annum. In this case what would manufacturers gain ?

In the first place in erecting their mills, (we deal with cotton in this case) the heavy outlay for engines and boilers, with foundations, chimney stack, and buildings can be omitted from their calculations, and electrical motors, either one to each machine, or one per section of mill, substituted. The cost of these motors, would total considerably less than steam plant of the same power.

Secondly, the large recurring outlay on wages of engine drivers,firemen, and coal trimmers, for oil and waste, repairs to engines and boilers, and for depreciation of plant, can practically be struck off the manufacturing cost once for all, as no special staff will be required to run the electrical motors, and maintenance and depreciation of these, is extremely small.

Thirdly, the power will be available day and night, for 365 days in the year, for £2 or Rs 30 per H. P. per annum.

Fourthly, a mill driven by electricity, will turn out better material than a steam driven mill, owing to the absolute regularity of the motion. I cannot conceive that a keen business man will hesitate a moment, in taking advantage of this offer, as it means, that we place a weapon in his hand, " cheap power " with which he can, and must defeat all opponents, who are handicapped by the heavy cost of steam. It therefore appears to me, that if the business men of India hesitate to take advantage of this offer, it means that new commercial blood is wanted, and we should not hesitate to obtain it from outside sources, if not forthcoming in India.

I therefore again strongly urge, that the proposed railway should be put in hand without delay, and pushed on to early completion.

Also, that Government should authorize an officer to meet manufacturers officially, and that he should be instructed with full powers, to enter into preliminary agreements, on the lines suggested above.

So far I have not mentioned Madras City, and the points on the East Coast, which in all probability will gladly take power. But it is useless discussing this question seriously at this stage, as I presume Government will not be inclined to put in more than 10,000 H. P. in the first installation, and users for this amount, will readily be found within easy reach of the Power Station.

As another instance, I feel confident that with a branch transmission line over the hills direct to Tinnevelly, we could deliver power there, for £4 or less.

Tinnevelly is the centre of the cotton growing district in Southern India. Cheap power at this point, would lead to the opening of new mills in the district, and as a natural consequence, the extension of the area under cotton, to supply the increased demand, would follow.

If the first installation of the Periyar power is undertaken by Government, I would point out that, apart from the engineering features of the scheme, the Chief Engineer Periyar Installation, will have a very heavy task before him in drawing up agreements with power consumers, and in acting as the electrical adviser, and contractor for plant. These agreements will have to be carefully considered in each case, and not only should the consumers have the terms and rate for their power settled, but I think Government, at any rate to commence with, should be prepared to advise and if necessary, obtain and put in the electrical plant required by consumers, that is to say Government should act as contractors for consumers, and put in, if requested to do so, the electrical plant required by them, at, say, a charge of 10% only, above the actual cost.

This aid would go a long way in deciding consumers who have had absolutely no experience of electrical machinery, in adopting the power.

I make this suggestion, as from my own experience on the Kolar Gold Fields, I found that in order to induce the mining companies to use the power, I had to supply and erect all the electrical plant for them, this plant was then purchased by the mines, after they had an opportunity to see that it worked satisfactorily.

One can readily understand the hesitation a man would have in adopting electrical power in India, where it is so difficult to obtain advice, if he were left to his own resources to instal the necessary plant. I therefore consider that it will be more or less essential, for Government to be electrical adviser, and contractor for the power consumers, in the first case.

It will not take long, for manufacturers to find out that the power is much simpler to instal and use than steam, and when once they know this, Government can retire from the post of electrical adviser, and contractor.

The above exactly describes what happened on the Kolar Gold Fields.

I cannot end this section of my report, without feeling that it is a little vague, and lacks preciseness, but I would repeat once more, that I could not definitely promise any thing to consumers on behalf of Government, nor could the managers I met, definitely promise any thing on behalf of their directors in England, this accounts for the lack of finality, which I feel is apparent.

However, I can assure Government, that a market for the power exists, and I consider that the development of even a small portion of the available power at the Periyar, will rapidly lead to the complete

utilization of this magnificent source of energy, which carries with it the possibilities of an expansion and development of the resources of Southern India, little dreamed of to-day.

Note.—Since writing the above I have received a letter from Messrs. Binny and Co., of Madras, which is given below.

It is needless for me to remark on this, except to say that the encouragement it offers to the development of the Periyar Power, is all that could be desired.

Copy of letter dated Madras, 17th June 1904, from Messrs. Binny & Co., to the address of Major A. C. Joly deLotbiniere, R. E.

ELECTRICAL POWER DELIVERED IN MADRAS.

With reference to the personal interview we had with you to-day, we write to say that we shall be glad if you can arrange for us to have the first refusal of 10,000 I. H. P. @ £7 per unit per annum, to be available day and night, for 25 years. It is understood that the power would be brought to a Central station in Madras, and would be supplied to no other user, within a radius of 15 miles from Fort St. George.

Section 3.

How is the work to be carried out ?

From experience gained on the Cauvery Scheme from its inception to its completion, I would venture to advise that in the event of Government deciding to carry out the project as proposed, the simplest and practically the only way to ensure the work being carried through to a successful termination, will be to proceed as follows.

I realize that my proposals will not fall in with the usual methods of carrying through a large work, but I submit that a work of this nature is very special, and quite out of the ordinary line. Under the circumstances, the P. W. D. rules must be considerably relaxed, especially those relating to the India Office Supply and Contract System, and absolute responsibilty and freedom of action given to one person, if the work is to be expeditiously executed.

Having settled that the work will be carried through, an Officer should be appointed to collect all the data required by contractors, to enable them to work out the actual details of the plant.

The necessary data will be,

1st. An accurate survey of head of fall.

2nd. An accurate section and contoured plan of the hill, on the line the penstocks will occupy.

3rd. Data as to minimum discharge of water.

4th. A contoured plan of ground to be occupied by Generating Station

5th. A survey, showing levels, and rivers to be crossed by the transmission lines, and data as to maximum flood in rivers, and greatest breadth at the point of crossing. The nature of the soil, jungle, and cultivation along the proposed line, should be noted.

6th. It will also be necessary to know the nature of the load the plant will work under, *i.e.*, the proportion of load for lighting, power purposes in mills, tramways, and industrial purposes generally.

7th. Meteorological data re-rainfall, thunder storms, and fogs, is also of great value in deciding on the type of insulators to adopt.

The Officer who has been entrusted with this work, should then proceed to Europe and America with this data, and before doing any thing else, he should make a trip to the various points mentioned in section 1 of this report, and study the conditions under which these plants have been installed. By conversing with the Managers of Stations, he will gain information as to the defects and merits of certain types of machines, which no books or Manufacturers will tell him.

He will also familarise himself with absolutely the latest advances in the practical working of Power Stations, Transmission Lines etc.

Another great value of a visit such as I propose, is the information which may be gained, as to the relative merits of the plant supplied by various firms.

Having seen all this, he should now be in a position to select some half dozen of the best firms in the Electrical, and Hydraulic line.

With the data which he collected in India, he can now call on these firms for tenders, and discuss with the Manufacturers on the spot, the conditions of contract etc., which he considers should be embodied in their tenders.

By conditions of contract, I refer to ;

1st. Scope of contract.

2nd. Guarantees of efficiency.

3rd. Method of payment.

4th. Arrangements for shipping.

5th. Size and heaviest weight of, any one piece.

6th. Dates of shipment of parts.

7th. Dates on which detailed plans of buildings will be submitted by contractors, after contract is awarded.

8th. When and where, contractors' responsibility for plant ceases.

9th. Experts for erecting plant.

10th. Provision of special trollies for hauling plant in India.

11th. Spares, and tools for erection.

12th. Amount of security bond to be deposited by contractor.

Such questions as housing the Contractors' Erectors in India, cost of living, medical attendance, and Insurance on Erectors' lives, all these have to be fully discussed and settled, before the tender is submitted.

I consider the contracts for Plant, should be given out to selected firms as follows.

Contract A should include :—

Penstocks, Head sluices, Expansion Joints, and Thrust Blocks.

Contract B,

Water Wheels for Generators and Exciters, and all interior piping in Generating Station, from Thrust Block to nozzles.

Contract C,

Lombard Governors.

Contract D,

The whole of the Electrical Plant in Generating Station including Step-Up Transformers, also all Section Station Plant, and the Plant for the two Step-Down Transformer Stations, including the overhead travelling cranes required.

Contract E,

Line wire, tie, and guy wire.

Contract F,

Insulators and pins.

Contract G.

Poles and cross arms.

In settling the conditions of contract, care must be taken to definitely state where the contract ends, for instance in the water wheels, if a solid connection is made between the wheel and the generator, it should be clearly stated in the contract, which of the firms will supply the other with the coupling template, also which of the firms supply the complete foundation drawings for the plant and building.

The dates of shipment for each contract must be so arranged that the plant will arrive at site when required, as if it all arrived at one time before the buildings were ready, the cost of store sheds would be excessive, and the electrical plant especially is liable to most serious damage, if by any chance, it should get damp in transfer.

If possible all electrical plant should arrive in India during the driest season of the year, in order to minimise risk of damage by rain.

The Electrical and Hydraulic contracts should both contain "blanket clauses" in which contractor undertakes to make good and supply at his own cost, all necessary plant and fittings omitted in his contract, necessary for the proper working of the whole.

The contractor should also agree, if, because of omissions, inaccuracies or defects in his specification or drawings, Government is put to any additional labor or expense, the cost of making good these defects, may be deducted from his bill.

The Officer entrusted with the work, should be authorised on receipt of tenders from the various firms, to select those he considers most advantageous to Government, and to complete the contract papers in every detail.

He will then return to India, and lay these before Government for final sanction.

If possible he should obtain foundation drawings from the contractors selected by him, for the Hydraulic and Electrical Plant, before he returns to India, in order to enable the Generating Station etc., being put in hand the moment the contract for Plant is finally accepted. This procedure will save months of delay, as it takes longer to build the stations in India, than to build the plant in Europe or America.

Having returned to India, and obtained the approval of Government to various tenders, the Officer in charge, whom I shall call the Chief Engineer of the Periyar Power Scheme, should at once set about organizing his Staff and putting work in hand.

I consider the following Staff will be necessary.

Chief Engineer in charge of Works.

Chief Electrical Engineer.

Assistant to the Chief Electrical Engineer.

Two Executive or Resident Engineers, (one for the Generating Station and Hydraulic work, one for the Transmission line and Transformer Stations).

Each Executive or Resident Engineer, should have one Assistant Engineer, attached to his Division.

The respective duties of proposed staff should be.

Chief Electrical Engineer, to make all necessary arrangements for handling the plant, from the time it reaches an Indian port, till it is erected finally in place. He should have charge of both Hydraulic and Electrical plant.

The Executive or Resident Engineers, will each be responsible for the foundations and buildings in their respective Divisions, and should at all times meet the wishes of the Chief Electrical Engineer, as regards changes or alterations to drawings.

The Executive or Resident Engineer of the line Division, will, apart from the buildings, have the carriage and erection of the poles and line in his charge, he shall be given the assistance of expert line erectors, during the laying out and erection of the line.

The Chief Engineer of the Scheme shall be under the orders of the Chief Engineer for Irrigation, Madras, and shall refer all important questions to him.

The Chief Engineer shall have charge, and be responsible for, the carrying out of the whole Scheme, and shall give orders to all Officers employed on the work. He will correspond direct with the Manufacturers, and must be given a comparatively free hand in all matters connected with the undertaking, and be permitted without further reference, to sanction changes in details, and replace small omissions from, or make additions to, original plant, if thought advisable.

In order to place the Chief Engineer, Periyar Transmission Scheme, in a position to accept the full responsibility for the work, he should be given full powers to sanction deviations from the original estimate, either way, to an extent of 5% on the total estimate. This is very necessary when it is remembered how rapidly changes for the better, are being introduced in Electrical Engineering.

The Chief Engineer should therefore be in a position to adopt the most advanced ideas, and incorporate them in the plant without delay, during the progress of the work. As a rule the advances tend towards cheapening plant.

This work if undertaken, will be a strictly business proposition, and when once put in hand, should be pushed through to completion, with the least possible delay.

It would therefore be most unfortunate if the Engineer in charge, was obliged to refer for approval to higher authority, on any point except questions of first class importance. My object in suggesting this is, to save delay, and above all to save mistakes being made in the scheme, due to ideas of men not specially qualified, who by the ordinary P. W. D. rules, would have a right to insist on their views being carried out.

I therefore suggest that the Chief Engineer in charge of the Periyar Scheme, should have one authority only to satisfy, which should be the Chief Engineer for Irrigation, Madras.

As far as all strictly technical details are concerned, the Chief Electrical Engineer will refer these to the Chief Engineer of the scheme for approval, and no Consulting Engineers will be necessary. From my experience of Electrical Consulting Engineers their opinions are frequently

given regardless of practical considerations, as to local conditions to be met, and therefore tend to do more harm than good, and often cause delay.

For the Cauvery Installation an Officer thoroughly well up in electrical questions, was appointed in England, who advised on points referred to him, made all payments to firms, and saw to the shipment of plant.

In the case of the Periyar, I would strongly advise a similar appointment, but in this case a whole time Officer will be required, as owing to the number of contracts, he will be obliged to be perpetually on the move, inspecting construction, and seeing to the shipment of plant by contractors, at the proper dates.

I would recommend that an officer of experience belonging to the Madras P. W. D. should be selected if possible for this work.

In the case of the Cauvery Installation, Captain J. H. Thomson late R. A., at present Chief Inspector of Explosives, under the English Board of Trade, was selected to do this work in England, but I am afraid his full time services, which will be necessary in this case, could not be obtained.

It might be feasible for the Chief Engineer of the Scheme himself, after his return to India with the tenders, to organize and set his Staff to work in India, and then return to Europe and personally see to the prompt shipment of all the plant etc. He would then return to India, and see the work of installation carried through.

As previously explained, the suggestions contained in this section of my report, are based on my own experience in carrying through the Cauvery Scheme. I have therefore corrected the procedure adopted in the above work when found not to work well, and I consider that the suggestions now made for the Periyar Scheme are workable, and should greatly facilitate the execution of the project.

Regarding the time for completion, I consider that it would take at least 9 months, for the Officer entrusted with the work to make the necessary investigations, and return to India with the tenders complete.

It would take 18 months for the last item of plant to reach site of works in India, from the date of acceptance of tenders.

It would take 9 months from date of last item of plant reaching India, to the preliminary trials of the plant, and finally two months' trials would be necessary, before the power was put commercially to work.

Preliminary investigations	9	months
Actual carrying out of project	27	,,
Trials of plant before taking service ...	2	,,

With good fortune the Periyar Power Installation might be in a condition to deliver power commercially, two years from the date on which tenders were finally accepted.

NOTE.—I have drawn up a set of General Conditions of Contract, which will be found as appendix, B to this report, this may prove useful as a guide for all contracts under this scheme.

Section 4.

Electrical power is applicable under ordinary circumstances, to every process in the Arts and Industries, which can be carried on through the medium of steam power.

At Niagara Falls, over 10,000 Horse Power is used in manufacturing bleaching powders, and other chemical products. The manufacture of Alluminium alone at Niagara, necessitates a use of some 20,000 H. P. Electric smelting of Iron ores has recently made such an advance, that it will only be a matter of a year or two, before the process is used commercially, on a large scale. Copper refining today is practically all carried out by the direct application of Electric currents.

In other countries, the advantage of Cheap Electrical Power has brought about a revolution in the industries of those sections of the countries, lying within the radius of that power. I cannot therefore help feeling that with cheap labor, and cheap power, the natural laws of supply and demand must come to be recognized, even in India.

Coming to the existing industries in India which may be directly benefited by cheap electrical power, I shall take the one which must appeal most to the people "En masse", that is agriculture. By the aid of electrically driven contrifugal pumps, water may be raised at an extremely low cost to high lying lands, which cannot well be reached by channels.

For instance take the case of a plot of land say 600 acres in extent, lying 20 feet above a channel. To irrigate this land we would require about 15 cu-secs.

Allowing that we use a main $\frac{1}{2}$ mile long, and 24 inches in diameter (cement or earthenware pipes would be quite strong enough for this main) in this case to pump 15 cusecs through a main $\frac{1}{2}$ mile long with 30 feet head (allowing 10 feet for friction) we would require to exert 45 H. P. continuously, say 50, to be safe.

The cost of this power if within 100 miles of the Periyar, would be at the rate of £5 per H. P. per annum; allow we used the power for 4 months. Then the cost for irrigating 600 acres of land would be $\frac{5}{3} \times 50 = £83 = $ Rs: 1245 plus the interest on the cost of pumps, motor, and the pipe line, which would cost about £1800, this at 5% = £90 = Rs: 1350. Therefore the total cost = Rs. 2595.

The assessment on the land, we might take at Rs. 5 per acre, or Rs. 3000.

In this case Government would profit to the extent of 5% on the sale of power in the first case, and also to the extent of nearly Rs. 1--per acre, on the land irrigated, but putting aside the profit, the gain to the community at large would be immense, if lands now lying waste and out of the reach of ordinary irrigation channels, owing to their elevation, could be brought under wet cultivation.

The example I have given, contemplates raising the water, clear 20 feet, and carrying it $\frac{1}{2}$ mile in pipes, the cost of a lower lift would be proportionally less.

I would also state that an ordinary intelligent native on a salary of Rs. 20 per mensem, could run the plant.

This view alone of the case, appears to me sufficient to warrant a development of the Periyar Power, now lying idle.

It may be interesting to mention that the Kerne River Power Company in California, devotes itself very extensively to this sort of work, pumping from deep wells, and that the results, both financially and mechanically, would appear to be good.

The Company have at present under contemplation, a project for transmitting power to be used for pumping and other duties, at a distance of 215 miles from the Generating Station.

I think this indicates that their existing plant has proved a success.

The question of Electric Lighting of Towns, Electric Tramways, and Power for Mills, has been discussed in section 2 of this report, but I venture to predict, that in a few years after the introduction of cheap power, the demand for the above purposes, will have very largely increased.

Regarding the propulsion of heavy trains on main lines by electricity, this is a most important question, and up to the present has not come into operation on a large scale, owing to the great cost of the equipment necessary, to supply continuous current over a great length of line.

It would appear however, that the leading Engineers of today, are on the verge of perfecting the "Single-phase system," which will revolutionise the question of the propulsion of vehicles over long distances on rail road lines.

The benefit to be derived from this system, is the small amount of current at high voltage, required for large amounts of power, and the consequent possibility of using an ærial conductor of small section, which fact removes a great difficulty from the application of electricity to Railways.

The single-phase motor, has also many advantages over the continuous current motor.

In an extensive system, if continuous current were used, the power would need to be distributed from several sub-stations containing either motor generators, or rotary convertors.

With the single-phase system however, the high line voltage which it is possible to use, practically does away with the need of these.

If sub-stations are necessary in long lines, with the single-phase system, these would contain nothing but Static Transformers, which require little or no attention.

Whereas as explained, the sub-stations with continuous current, would require rotary convertors, or motor generators, to convert the alternating into continuous current, and these require constant attention.

The cost of equipping the line therefore, with the single-phase current system, is much below that for a continuous current one, and the power lost in transmission is greatly reduced, as well as the cost of maintenance being much less.

Generally speaking, the saving in plant in equipping a line with the single-phase, as compared to continuous current, should amount to at least 20 per cent.

From a general view of the present situation it would therefore appear probable, that in a year or eighteen months from now, when all details are perfected, the great and many advantages possessed by the single-phase current, will render the equipment of main lines with electrical traction, one of common occurrence.

This will especially be the case in countries where coal is dear, and water power cheap.

Under the circumstances, I feel that the equipment of railways in Southern India with electrical traction, is only a matter of a few years, if the Periyar project is carried out.

A. J deLOTBINIERE, Major, R.E.

APPENDIX—A.

APPENDIX—A.

Circular Letter No. 1.

Bangalore, Dated 20-5-04.

From

MAJOR A. J deLOTBINIERE, R.E.,

Superintending Engineer, W. C., Bangalore.

Sir,

I have been entrusted by the Madras Government with the preparation of a scheme for the generation and utilization of electrical power from the Periyar Project for industrial purposes in Southern India.

2. It is hardly necessary for me to point out to practical men that the first consideration in any scheme of the sort is, **a market for the power.**

3. To arrive at an idea of the probable demand, I propose to collect as far as possible statistics of power actually employed at present, and when possible estimates of requirements for extension of existing plants, and of new cunsumers.

4. As has been amply proved again and again in America, and on the Continent, and at the Kolar Gold Fields in this country, it is possible to supply electrical power generated by water at a considerably cheaper rate than that at which power from coal or oil can be generated, provided that the supply is on a sufficiently extensive scale, and that the distance from the source of power is not too great.

5. Cheap power needs no advocacy from me, I trust therefore you will assist me by filling in the attached forms and giving me any other information you think will be usefull, especially regarding new consumers.

6. In filling in the enclosed form which kindly return to me with the least possible delay, I would draw your attention to the notes below.

Note.

A. The introduction of electrical driving, in place of steam or oil engines, should not entail any interference with existing installations, the change would be made by simply placing a motor in such a position that the motor pulley can drive the shafting by ropes or belts.

B. In no case need the existing engines be removed. In the case of tramways, alternating motors, would be used to drive existing dynamos, and for electric lighting, the three phase alternating current supplied, would be used direct.

C. High Voltage three phase alternating current, between 25 and 60 cycles, will be employed for transmission purposes. This will be reduced to a medium voltage for local distribution in towns, and by means of secondary transformers on consumers' premises, the voltage will be still further lowered for driving motors, or lighting.

D. Induction motors, by for the simplest electrical machine for power purposes, will be used.

E. By means of Rotary Converters or Motor Generators, direct current for trams or industrial purposes, &c., may be obtained.

F. The power will be available continuously day and night.

G. The whole plant including transmission line will be in duplicate, which should ensure an unfailing supply of energy to consumers.

7. Regarding the cost of power, this will naturally vary with the distance from its source. But if the demand is sufficient, I am in hopes of being able to offer electrical power, at from 15% below cost of steam in Madras, and from 50 to 60% below cost of steam at points situated within 100 miles from the power station.

The many advantages of electrical power, as compared with steam power, are too obvious to call for comment. It may however be stated, that manufacturers in other countries have in many cases adopted it, in districts where steam power could, on account of the cheapness of coal be generated at less cost.

8. I may mention that this communication is not in any way official.

9. Trusting that you will give me your hearty co-operation in this matter, which I anticipate will lead to a great advance in the industrial development of the Presidency.

I beg to remain,

Sir,

Your obedient seavant,

Superintending Engineer, Western Circle.

QUESTIONS ASKED.

No.

1. What I. H. P. do you now use at your works..................................

2. What does the load mainly consist of..

3. What is the present cost to you per annum per I. H. P. taking into consideration, the cost of fuel, wages of drivers, fireman, &c., oil and waste, repairs to engine and boilers, and depreciation.

4. Is your reply to question 3, based on your plant running 10, 12 or 24 hours daily..

5 In the event of Government deciding to undertake the generation and supply of electrical energy to your district, would you be prepared to adopt this electrical power in place of your present source, if the power was made available for you at a reduction of 20% or more below the cost of steam...

6. Please state if in your opinion a reduction in the cost of power of from 20 and 50 per cent. below the present cost of steam would induce your firm to consider an enlargement of their existing plant...........

7. General remarks..

APPENDIX—B.

APPENDIX—B.

General Conditions of Contract for the Supply on Rails at a Port in India, of the Electrical Plant required in connection with the Periyar Power Transmission Installation, to Madura and Trichinopoly, in the Madras Presidency.

Scope of Contract.

1. The Contractor agrees to supply the necessary materials, and electrical plant, provide suitable packing, and also sea and rail carriage from his works to a port in India, and deliver on rails at port (subject to provision in clause 29). The plant will be delivered to the Madras Government Officials after its having been unloaded and delivered on rails at said port. The Contractor also agrees to insure the plant against all and every risk, for the first twelve months after it is shipped.

Members of the Government, etc., not to be Personally Liable.

2. Nothing in this contract shall be deemed to impose any personal liability on any member, officer, or temporary servant of the Government.

Definition of Terms.

3. In construing these conditions and specifications, the following terms shall have the meanings herein assigned to them respectively—that is to say :—

"The Government" shall mean the Government of Madras.

"The Government Engineer" shall mean the Chief Engineer of the Periyar Power Transmission Installation, or his deputy duly authorised by him, to act in his stead in Americal England, or India.

"Contractor" shall mean the firm or company contracting for the works herein specified, whose tender is accepted by the Government, and shall include their heirs, executors, administrators, successors and assigns.

The term "Plant", "Works", shall mean all works to be done and materials to be furnished by the contractor under this contract, and conditions of contract, and shall include the whole of the electrical apparatus with subsidiary items, necessary for the Generating Station and subsidiary buildings about the same, for the Section Stations along the line, and for the Step-Down Transformer Stations at Madura and Trichinopoly, and all spare parts as provided in section 10 hereof, which may be found necessary to carry out in a thoroughly successful manner the object of this contract, *i.e.*, the delivery at Madura and Trichinopoly of 5,000 H. P. respectively, in other words power capable of operating at each of these places simultaneously, of a total rated capacity of 5,000 H. P. and each of the individual motors must be fully loaded.

"The expression "Tender" shall mean the lump sum for which Contractor agrees to carry out the contract.

The expression "Month" means one calendar month.

Drawings and Specifications.

4. The Contractor must submit complete general and foundation drawings, and specifications of the whole of the plant and apparatus included in the Tender, and he must also submit specifications, drawings, or prints as required, within ten days of the Government Engineer's notification to the Contractor that his tender has been provisionally accepted by him.

Where drawings and specifications are referred to as being supplied to the Government Engineer, it is understood that the same are delivered in duplicate, free of cost, if required one set to the Government Engineer in England, and one to the Government Engineer in India. The aforesaid drawings and specifications, after having been approved and signed by the Government Engineer, shall be deemed to be the working drawings of the contract. They shall become the the property of the Government, and shall not be departed from in any way except by the written consent of the Government Engineer. The Government shall not be held responsible for any mistakes that may arise, through the use of drawings and specifications supplied by the contractor.

Language and Law of Contract.

5. The contract and all other documents in relation thereto, shall be in the English Language.

Lump Sum Contract.

6. The annexed tender, which is not to be detached from the Conditions of Contract and Specifications, is to be filled in with the payments required for the whole of the work mentioned in Clauses 1 to 29 inclusive, in these conditions.

Payments.

7. The Contractor is also required to name the Tender under the heading :—

"Price of plant, including freight and insurance, on rails at port of debarkation (subject to provisions of clause 29)."

On the basis of this Tender, payments on account will be made in London, to an authorised agent of the Contractor, by the Government through the India Office or some authorised agent of the Government, on the certificate of the Government Engineer.

1. At date of contract—10 per cent. of tender.
2. Upon shipment and persentation of bills of lading, 50 per cent of Tender, pro rata to shipment.
3. 15 per cent of Tender pro rata to shipment, three months after arrival at Indian Port, and 15 per cent. of Tender pro rata to shipment, six months after arrival at Indian Port.
4. At six months after the plant has been put in operation if working to the satisfaction of the Government Engineer and up to the Company's guarantee, the final 10 per cent of Tender shall be paid by the Government. If however, the completion of the work in India shall be delayed for any cause not attributable to Contractor, for a period of 18 (eighteen months) after the arrival of the plant in India, then in that case the unpaid balance of the Tender shall become due and shall be paid at once.

8. The Contractor shall send an Agent to India who shall be present at the unloading and who will hand over the plant to Government in first-class condition on rails at Indian Port. The Government will be glad to give this agent every opportunity to visit the works during the erection of the plant, if the Company decide to keep him in India. His presence might also facilitate and expedite communication between the Government and the Company, in the event of changes etc. being decided upon in the plant, during its erection.

It is to be clearly understood however, that this Agent will not have any authority over any person in the pay of the Government, or any part or portion of the plant, after it has been handed over to the Government, but his advice and presence. under these conditions, may prove of great value to the Government.

9. The contractor agrees to supply the Government with erectors for erecting the plant supplied, if called upon to do so, under the conditions contained in the agreement dated......................This agreement will be a separate instrument.

10. The Contractor, though not responsible for the operation of the plant, undertakes for the first six months of its operation, to provide sufficient spare parts to keep the plant in first-class working order. The Contractor also agrees to make no extra charge, over the lump sum entered in this contract for spares supplied to Government under this Clause, for making good defects and deficiencies, or renewals due to the same, which may be necessary during the time specified, *i.e.*, first six months' operation.

11. The Contractor will be required to find two good and substantial sureties, or give the bond of a surety Company satisfactory to the Government, to be jointly and severally bound with the Contractor, in a sum of £............................(............................) for the purpose of securing the due fulfilment of the contract, according to the true intent and meaning of the Tender, Drawings, Specifications, and General Conditions thereof.

Power to determine or re-let Contract.

12. If the Contractor shall go into liquidation whether by voluntary resolution, or by order of the Court, or shall stop business, become insolvent, or suspend or obviously delay the execution of the Contract, or shall refuse or neglect to proceed with the works to the satisfaction of the Engineer, the Government reserves the right to, and may after giving seven days notice in writing, enter upon and take possession of the works, and all plant, machinery, materials, implements, and tools, such articles becoming the absolute property of the Government by virtue of the payments made, or to be made as stated in Clause 7, and all costs and charges incurred by the Government in ending this contract, or re-letting to other Contractors, or in completing the whole of the works, as required by these conditions, shall be set off by the Government against all money due, or to become due, to the Contractor.

Insurance.

13. The insurance mentioned in clause I shall be for the full value of the plant, and shall be in the name of and for the benefit of the Company and Government, in proportion to payments made thereon by the Government.

Arbitration.

14. Should any doubt, dispute, question or controversy arise between the Government, or the Government Engineer as their representative, and the Contractor, touching the contract, or any matter in any way connected

with the contract, or the operation thereof, or the rights, duties or liabilities of either or any party, or parties, in connection with these premises, then either party may, within twenty-one days, but not later, give to the other notice in writing of the existence of such dispute or difference, and such dispute or difference shall be referred to such person as may be mutually agreed upon, or in the case of difference upon this point, as shall be nominated by the President of the Institution of Electrical Engineers for the time being, whose decision and award shall be final and binding between the said parties.

Contractor shall pay all royalties and indemnify the Government against Claims.

15. The Contractor shall pay all fees and royalties leviable on all articles protected by letters patent, supplied to the Government, or used or to be used, on any portion of the plant to be supplied, and shall indemnify the Government and every member or officer thereof, against any action, or loss, consequent on any infringement of patents.

Government Engineer's power to alter design of plant or Method of Construction.

16. The Government Engineer may require such alterations to be made in the plant or method of erection, during its progress, as he may deem necessary, and, after due consideration of the relation which such alterations bear to the work and prices provided under the contract, will agree with the Contractors as to the amount if any, that shall on that account be added to, or deducted from, the contract price.

No extra work, for which the Contractor may claim payment at the Manufacturer's works will be allowed, unless upon the signed order of the Government Engineer.

Time for Completion.

17. The time for completion of supply and delivery on boardship at port of embarkation of the whole plant under this contract, shall not be later than..........................from the date of acceptance of Tender by Government, and the approval of the plans by the Government Engineer. Within seven days of receipt by the Contractor of a notice from the Government Engineer to commence work under this contract, the Contractor shall commence to execute, build and construct, and otherwise prepare the plant for the work to be carried out under this contract.

Damages for Delay in Completion of Contract.

18. In case the contract, or the works detailed therein to be executed by the Contractor, shall not be completed in the time appointed, or within such limits of time as may be, at the discretion of the Government Engineer, authorised by him in writing, Government shall be at liberty to deduct from sums of money then due or to become due to the Contractor, hereunder, as and for liquidated damages, and not as or by way of penalty, such a sum per month as shall be equal to 2 per cent. on the contract price of the plant as entered in the tender. In the event of such delay being caused by the act of God, a strike or other dispute of the workmen, or fire, or destruction of the Contractor's works, or by loss or damage at sea, or by any other case which was unavoidable and could not be foreseen or evercome by the Contractor, then and in such event, the liquidated damages shall not be payable for the period exempted by the Government Engineer, and the time for the performance of this contract shall be extended for such period as may be fixed by the Government Engineer.

Testing.

19. At the expiration of the six months' operation by Government, the Government Engineer will make a full test of the plant to prove that it fills all the conditions laid down in the Contractor's specifications. If the working of the same gives a result equal to the Contractor's guarantee and specification, these tests will be accepted as conclusive evidence that the Contractor has fulfilled his contract.

Suspension of Work.

20. The Government Engineer will have power to suspend the execution of the works or any portion of them, should he consider it necessary from any reasonable cause, without the Contractor being allowed any extra payment except as provided for in clause 7, but the period of such suspension shall be considered as extending the time guaranteed by the Contractor for the completion of the works, under this contract.

Government Engineer's Certificate.

21. No plant shall be accepted by the Government, and no work shall be considered ready for acceptance, until the Government Engineer shall have signed a certificate that the said plant or work has been inspected and approved, and if within six calendar months after the date of the final certificate of erection signed by the Government Engineer, any defects shall be discovered in the plant, or there shall be any deficiency in the quantities of work contracted for, due to inferiority of material, or workmanship, or omission on the part of the Contractor, the defective or deficient articles shall be replaced by the Contractor, free of cost to the Government, notwithstanding any inspection or approval that may have taken place in England, India, or in other countries.

No approval on behalf of Government to Relieve Contractor from Liability.

22. No approval, consent, requirement, or other act or thing, given, made or done, by the Government Engineer, or any of his representatives, shall in any way relieve the Contractor from any of his liabilities in respect to this contract.

23. Government undertakes to instal and erect, the whole of the plant in strict accordance with the working drawings and plans supplied by Contractor, and Contractor will not be held responsible for failure of the plant, in the event of the plans having been departed from by Government, unless the departures have been made at the suggestion of or with the approval of Contractor.

24. The Contractor shall supply at 5 per cent. above cost price, all tools and machinery for erection, which the Government Engineer may call for.

Packing.

25. The Contractor shall take the entire responsibility of packing the plant to ensure its being safely delivered on rails at port in India, and any parts of appartus that may be broken or otherwise damaged on arrival at the works, because of insecure packing, shall be rejected by the Government Engineer, and must be replaced free of cost to Government, by the Contractor.

Weights to be Marked on each Package.

26. Each package or part of the plant should have its weight painted on in a conspicuous place. The Contractor must also supply the Government

with complete shipping specification for each and every shipment of goods. No piece of plant when packed shall weigh more than tons, or be above the following dimensions. Length, breadth, depth, over all.

27. The Contractor agrees to ship the plant to India in sequence as it may be required for erection, as for instance, base plates and holding down bolts, together, or with the generators: in other words the plant will be delivered in such sequence, that the non-delivery of any part will not retard the erection of other parts already delivered.

The first shipment of plant should be made within seven months of signing contract.

No shipment should be less than 150 tons in weight.

Hydraulic Plant.

28. The Government is contracting with for water-wheels, and the Contractor agrees to exchange templates, drawings etc., with that Firm.

The Government agrees to furnish all necessary Hydraulic Plant, and to instal and maintain the same in a suitable and satisfactory manner, for the operation of the generators and exciters furnished by the Contractor. The Government shall supply water-wheels of the self contained Impulse type, with horizontal shafts, and shall arrange said shafts at suitable heights above foundations to suit the Contractor's generators and exciters. Government shall supply suitable couplings approved by the Contractor, to connect the shafts of water-wheels, with those of generators and exciters.

The Government agrees that the following conditions deemed necessary for the successful opperation of the plant, shall be fulfilled by the water-wheels supplied by them :—

(1). The water-wheels for driving the generators shall each deliver to the corresponding generator shaft under normal conditions, 2,800 Brake Horse-Power, and a maximum of 3,500 Brake Horse-Power. The water-wheels for driving the exciters, shall each deliver under normal conditions, 400 Brake Horse-Power.

(2). The regulation of all the water-wheels shall be as follows :—

If 25 per cent. of the full normal lead be thrown off or on instantaneously, the increase or decrease in speed is not to exceed 2·5 per cent. of normal speed. If 50 per cent. of full normal load be thrown off or on instantaneously, the increase or decrease in speed will not be greater than 4·5 per cent. of the normal speed. If the full normal lead be thrown off or on instantaneously, the increase or decrease in speed will not exceed 9 per cent. of the normal speed. Further-more, the governors shall not race under sudden variations of load, and in steady or gradually changing loads, they shall not allow a variation in speed of more than 1 per cent. from the normal.

Customs Duties to be Paid by Government.

29. The Government agrees that they will arrange, and pay on their own account, all custom duties, port taxes, and landing charges, in British India.

Government of Madras.

PUBLIC WORKS DEPARTMENT

IRRIGATION BRANCH.

NOTE

ON

UTILIZATION OF WATER-POWER, PERIYAR PROJECT.

WITH APPENDICES.

MADRAS:
REPRINTED BY THE SUPERINTENDENT, GOVERNMENT PRESS.

1904.

NOTE ON UTILIZATION OF PERIYAR WATER-POWER.

THE Periyár lake is a large reservoir lately constructed by the Irrigation Department of Madras in the Travancore Hills which separate the Native State of Travancore from the Southern Presidency of India. The lake which is situated between 2,000 and 3,000 feet above sea level is formed by a masonry dam 155 feet high thrown across the valley of the Periyár river and by means of a tunnel through the watershed dividing Travancore from British territory, part of the flow of the Periyár is diverted from the well-watered land of Travancore to the comparatively dry district of Madura in British territory. This work is ably described in a paper by Colonel J. Pennycuick, C.S.I., R.E., read before the Institution of Civil Engineers in January 1897. Although undertaken primarily for irrigation purposes the situation of the work over 1,000 feet above the level of the plains on the British side lends itself favourably to the development of mechanical power and in 1892 Mr. A. Chatterton, Professor of Engineering of the College of Engineering, Madras, made a proposal to use the power for the manufacture of aluminium. In 1893 the subject of utilizing the water-power derived from the Periyár works was referred to a Committee composed of Professors Unwin, Forbes and Roberts-Austen and Colonel Pennycuick whose report is appended.

2. In addition to the proposal to utilize the power for the manufacture of aluminium, enquiries have been made with reference to the power being used for purposes of electric traction and for electric lighting and more recently the utilization of the power for the manufacture of carbide of calcium has been considered.

3. The latest decisions of Government on the subject are embodied in the appended notice calling for tenders for the utilization of the power, the date up to which tenders will be received having now been fixed as the 1st July 1898. Attention is directed to the second paragraph of the notice from which it will be seen that the quantities of water and head now taken to be available are different to those assumed by the members of the Committee of 1893. Hitherto there has been no cause however to expect that the continuous available supply will ever fall to less than 500 cubic feet per second during the cultivating season.

4. A map of that part of the Madura district lying below the lake accompanies this note, as also a railway map showing the general situation of the lake and district with reference to towns and railways in this part of India.

5. The distance 6,800 feet given in the notice as that from the mouth of the tunnel to the foot of the hills is taken from a level section along the course of the stream from the tunnel, but it would probably be inadvisable to lay pipes along this line. The accompanying photograph shows the nature of this stream a little more than half a mile from the tunnel exit. The stream up to this point winds between hills densely covered with forest and descends in a series of cascades over sheets of rock and large boulders with which its course is strewn. The fall in the stream at the bridge from the tunnel exit is 305 feet. When the view was t[illegible] the Periyár lake was one foot above full lake level, and the tunnel was discharg[illegible]g full, the flow in the stream being calculated at 1,040 cubic feet per second.

6. Below the bridge the course of the stream is similar to that above until it approaches the plains when it flows through a deep valley, the action of the water cutting away the soft soil and widening its course until a permanent channel has been obtained. The fall of 900 feet mentioned in the notice has been taken to the nearest ground on the river bank that is thought flat enough to build on conveniently but a considerably larger fall can be obtained by going further down stream. A site for works can be obtained about 2 miles south-west of the Kuruvanuth village shown on the map. Building stone can be obtained from the hills close by, limestone is on the spot, and excellent timber can be obtained at Thekady or from the neighbouring forests.

7. The distance from Kuruvanuth to the nearest railway station (Ammayanáyakkanúr) is 78 miles. Periyakulam on this road has a population of 16,000 and Uttamapalaiyam and Chinnamanúr about 5,000 each and Butlagundai something more. The other places on the road are but small villages. The road however is the main road into Travancore.

8. The following are possible applications of the power available :—

Manufacture of carbide of calcium.
Do. do. of aluminium.
Electric traction on railways.
Cotton mills.
Electric lighting.

Of these possibly the first is most promising. The report of the Chemical Examiner on specimens of limestone obtainable at the places shown on the map is appended to this note. Charcoal can be manufactured from the timber of adjacent forests.

The only large towns within about 100 miles from Kuruvanuth are Madura 80 miles with a population of 80,000, and Trichinopoly 72 miles from Ammayanáyakkanúr, population 80,000. Tanjore with a population of 50,000 is 31 miles beyond Trichinopoly. The nearest seaport is Tuticorin 90 miles from Madura.

MADRAS,
November 1897.

(Signed) W. HUGHES,
Chief Engineer for Irrigation.

Appendices to this Note.

I. Notice calling for tenders published in *Fort St. George Gazette*, dated 15th June 1897.

II. Report of the Committee appointed to consider the question of the utilization of the water-power.

III. Photograph of stream from tunnel. (*Note.*—This has not been reproduced).

IV. Description of lime specimens. Extracts from Sub-divisional officer's report. Report and analysis of the Chemical Examiner.

V. Periyár Map.

VI. South Indian Railway Map.

APPENDIX I.

NOTICE.

WATER-POWER.

PERIYAR LAKE—MADRAS PRESIDENCY.

TENDERS are invited for the utilization of water flowing from the Periyár lake for purposes other than irrigation and not incompatible with the use of the water for drinking.

2. The irrigating season extends over nine to ten months, during which time the discharge is likely to be from 1,100 to about 500 cubic feet a second according to the demands for irrigation and the available quantity in the lake. Subject to the risk of interruption by accidents or drought, a supply can be given throughout the irrigation season. No supply can be guaranteed at other times, but, so long as water is available, the Government will be prepared to issue it in such daily quantities as may seem to it advisable with reference to the time which is likely to elapse before the supply is replenished by the setting in of the rains.

3. The fall from the tunnel to the foot of the hills is approximately 900 feet, and the distance measured along the course of the stream about 6,800 feet. One cubic foot per second falling 900 feet is estimated to produce over 60 effective horse-power.

4. Intending lessees should state the quantity of water required in cubic feet per second and the annual rent offered for each cubic foot per second. No rent will be charged for the first year from the date of the concession; for the second year the charge will be one-fifth, and an additional charge of one-fifth will be made every year until the full rent is reached. The whole or part of the concession may be surrendered on a year's notice being given.

5. Lessees will construct at their own expense, on plans to be approved by Government, all the weirs and other works required to divert the water from the river below the tunnel.

6. For further information, application may be made to the Chief Engineer for Irrigation, Madras, by whom tenders will be received up to 31st October 1897.

A. R. KNAPP,
for Joint Secy. to Govt., P.W.D., Irrigation Branch.

Ootacamund, 28th May 1897.

APPENDIX II.

Public Works Department, Madras.

REPORT

OF THE

COMMITTEE APPOINTED TO CONSIDER THE QUESTION OF THE UTILIZATION OF THE WATER-POWER

DERIVED FROM

THE PERIYÁR IRRIGATION WORKS.

PUBLIC WORKS, No. 6.
INDIA OFFICE, LONDON, *24th August* 1893.

To

His Excellency THE RIGHT HONOURABLE
THE GOVERNOR IN COUNCIL,
Fort St. George.

MY LORD,

In accordance with the request contained in your Public Works Letter, No. 14/3472, dated the 20th December 1892, steps have been taken in this country to obtain the best available professional opinion on the subject of utilizing the water-power which will be available on the completion of the Periyár Irrigation Works.

2. A Committee composed of the following gentlemen was appointed to consider the question :—

Professor W. C. UNWIN, F.R.S.
Do. G. FORBES, F.R.S.
Do. W. C. ROBERTS-AUSTEN, C.B., F.R.S.
Colonel J. PENNYCUICK, R.E.

3. This Committee have submitted a report, which I now forward for your Excellency's consideration, and for such action as may be possible in the development of this important undertaking.

* * * * *

I have the honour to be,
My Lord,
Your Lordship's most obedient, humble Servant,

KIMBERLEY.

ENCLOSURES.

No. 1.

Report of Committee on Utilization of Water-power at Periyár Works.

It is clear from the facts laid before the Committtee that, on the completion of the works for the diversion of the Periyár river, a large amount of power will become available for industrial purposes, and that the development and utilization of this power will be of the greatest importance to the Government of India from an administrative as well as from a financial point of view.

The subject naturally divides into two main branches, firstly, the development of the power at the site of the works by suitable hydraulic apparatus, and, secondly, its utilization on the spot, or transmission to distant places at which it may be more effectively utilized, and the Committee are of opinion that the best method of dealing with these questions will be by separate notes, drawn up by the individual members of the Committee, whose technical knowledge and previous experience best qualify them to deal with the separate branches of the enquiry.

Unfortunately, at the last moment, Professor Unwin, being on the eve of his departure for America, thought it better to withdraw from the deliberations of the Committee, and has only been able to report very briefly on the hydraulic arrangements for the development of the power at the site of the works, a subject with which he was eminently fitted to deal, and an additional note on this point has therefore been drawn up by the Chairman of the Committee, Colonel Pennycuick, R.E.

The notes of individual members are attached to this report, and a reference to them shows that the development of the power at the site of the works would not cost more than 4*l.* per horse-power for the hydraulic apparatus alone, and that the electrical apparatus for its transmission to Madras would not cost more than 35*l.* per horse-power delivered at that city, while for the towns of Madura and Trichinopoly the cost would be not more than 23*l.* and 17*l.*, respectively, the most important item of the cost of transmission being that of the conductors, which depends directly on the distance.

Making due allowance for interest on first cost, and depreciation of plant, it appears that power can be delivered in the three towns named at an annual cost per horse-power of 3*l.*, 2*l.* and 1*l.* 10*s.*, respectively, and, comparing this with the cost of steam-power, there would seem to be every probability that a large portion of the available power can be profitably used in the towns in question as well as in the smaller towns on the road thereto.

The most obvious, and probably the most profitable, mode of utilizing a large portion of the power would be for the lighting of the towns within reach. The Committee understand that none of these towns are supplied with gas, and that in Madras especially the cost of lighting by oil lamps forms a considerable portion of the municipal expenditure.

The information before the Committee as to the nature of the corundum deposits of Southern India is insufficient to enable them to form a positive opinion as to the advisability of using any large amount of power in the manufacture of aluminium, but it is certain that the estimates contained in Mr. Chatterton's original memorandum were over-sanguine.

It is probable that a substantial amount of power might be usefully employed in the immediate neighbourhood of the works in the driving of wood working and cotton machinery. No cotton is believed to be grown in the immediate vicinity of the works, but large quantities are said to be produced in the neighbouring districts of Coimbatore and Tinnevelly, in both of which districts large mills are at work. The advantage of cheap power would probably more than cover the cost of carriage of the raw material to and from the site of the works.

The Committee concur in the opinion expressed by the Chief Engineer to the Government of Madras, that the water should be brought to the hydraulic motors by means of pipes, a separate pipe being used for each motor, or two motors at most being supplied from a single pipe, and that, with a view of reducing as far as possible the cost of the pipes, the fall should be divided into either two or three stages.

They do not consider that it is absolutely certain that it would not be found possible to convey the whole of the water to the foot of the fall by a single inclined shaft sunk through the rock, and if such a course were practicable its cost would probably be somewhat less than the cost of pipes, but they do not think that the chance of a saving in first cost is such as to justify the heavy initial expenditure involved in the detailed examination of the rock which would be necessary before the construction of the shaft could be undertaken. They also observe that the shaft must be constructed once for all for the whole quantity of water likely to be ultimately brought into use, while the pipes can be put down from time to time, as the utilization of the power is developed.

The Committee also concur in the Chief Engineer's opinion that the construction of a railway from the nearest point of the South Indian Railway to the site of works, a distance of about seventy miles, is a necessary preliminary to the utilization of the power in question. How far such a railway could be expected to pay interest on the cost of construction from ordinary traffic is a point on which the Committee have not sufficient information to enable them to form an

opinion, but looking to the fact that the greater part of the line will pass through country already fertile or about to be fertilized by the irrigation from the Periyár, and that it will connect the second largest town in the Madura district with existing lines of railway, they think it improbable that the deficit will be such as to outweigh the advantages to be gained by the utilization of the water-power under consideration. Such a railway might be easily and economically worked by electricity, for which it would be especially suitable, as for many years to come it must remain an isolated line, connected with other lines only by the single junction with the South Indian Railway at Ammayanáyakkanúr.

In the note of the Chief Engineer to the Madras Government, dated 17th October 1892, it is said that provision must be made for closing the head sluices at the Periyár for a fortnight in every year for the purpose of inspection and repair. Such closing would be a very serious obstacle in the way of the utilization of the power for electric lighting or for the working of railways; whether it can be avoided is a matter for the consideration of the professional advisers of the Madras Government, but the Committee are informed by their Chairman that he thinks there would be no serious difficulty in so arranging the sluices that a certain minimum quantity of water could be sent down at all times, and that the cost of such an arrangement would be insignificant as compared with the importance of the object in view.

It does not appear to be within the province of the Committee to offer an opinion as to the exact course to be adopted in order to bring into use the power under consideration. It is for the Government of Madras to consider whether they will themselves construct the whole or any portion of the apparatus necessary for the purpose, or whether they will simply lease the right to the use of the water to one or more contractors leaving the latter to make their own arrangements for its utilization.

The Committee would, however, suggest that early steps should be taken for giving the utmost possible publicity to the fact that this power will shortly become available, with a view to the submission of practical proposals for its development.

It must be borne in mind that there is a great probability of new industries being attracted to the district by the mere existence of a source of power, which appears to the Committee to be one of the cheapest in the world.

JOHN PENNYCUICK, Colonel, R.E.,
Secy. to the Govt. of Madras, P.W.D.

GEORGE FORBES,
W. C. ROBERTS-AUSTEN.

13*th July* 1893.

No. 2.

Note by Colonel PENNYCUICK, *R.E., on the Hydraulic Apparatus required for developing the Water-power of the Periyár River, dated* 28*th June* 1893.

It may be taken as certain that the water required for driving the hydraulic motors will be brought to the latter by iron or steel pipes, a separate pipe being provided for each motor, or pair of motors, and that no attempt will be made to carry the whole of the water-supply by a single shaft or inclined tunnel sunk in the rock on the sides of the valley down which the water is passed.

The side slopes of the valley are such that there will be no difficulty in laying the pipes with a slope of $2\frac{1}{2}$ or 3 horizontal to one vertical, and the average length of the pipes may be taken at three times the head.

The total fall available is a little over a thousand feet, and as a small amount will be lost at each stage if this total fall be divided into two or more stages, the effective head may be taken without sensible error at a thousand feet.

So far as the pipes are concerned, the cost per unit of power is pretty nearly independent of the size of the pipes for any given velocity and head. The power that can be conveyed by a single pipe varies as the square of the diameter, while the cost varies as the diameter multiplied by the thickness, and as the latter varies as the diameter for a given pressure, the cost varies in the same ratio as the power. In reality the cost is rather less for large pipes than for small ones, as the loss of head to produce a given velocity is greater in the latter case than in the former. This difference is not of importance in pipes over two feet in diameter.

The cost of the pipes is, however, very seriously affected by the number of stages into which the total fall is divided. Thus, a pipe three feet in diameter utilizing the fall of a thousand feet in a single stage would require a thickness at the bottom of about an inch and a half, and a mean thickness of seven-eighths of an inch. If the fall were divided into two stages the maximum and mean thickness would be three-quarters and half-an-inch; for three stages they would be one-half and three-eighths, and for four stages three-eighths and five-sixteenths, showing a reduction of thickness, and consequently of cost, in the proportion of 14, 8, 6 and 5.

On the other hand, there is a certain loss of head at every stage, the cost of the head-works and regulating gear is practically independent of the height of each stage, and therefore increases directly with the number of stages; and the cost of three turbines of a thousand horse-power would be considerably greater than that of a single turbine of three thousand horse-power.

The exact number of stages which would give the most economical result will vary according to the size of the pipe and the velocity allowed, but within the limits with which we have now to deal, it may be said broadly that there is considerable economy in an increase from one stage to two, not much in an increase from two to three, and little or none in any further increase. The further calculations in this note will be made on the assumption that the fall is divided into two stages of five hundred feet each, the pipe for each stage being fifteen hundred feet long.

The velocity of discharge permissible in the pipes exercises a most important influence on the cost of the latter per unit of power, the absolute cost being independent of the velocity, while the power transmitted increases in direct ratio thereto, except that the loss of head required to generate the velocity increases somewhat rapidly in proportion to the latter. Taking, as an example, the case of a three-foot pipe fifteen hundred feet long, with a total fall of five hundred feet, the result for different velocities would be—

Velocity per second.	Loss of head.	Effective head.	Horse-power.
	FEET.		
$2\frac{1}{2}$	1	499	727
5	4	496	1,446
$7\frac{1}{2}$	9	491	2,148
10	15	485	2,829
$12\frac{1}{2}$	22	478	3,485
15	32	468	4,095

the cost of the pipe being the same in each case.

The economy of high velocities is more marked in the case of larger pipes and less so with smaller ones.

So far as mere economy in the cost of the pipes is concerned, velocities of fifteen or even twenty feet per second might be used with advantage, but there are practical objections to the use of velocities much exceeding ten feet per second, and this limit will be adopted in the following calculations.

In Professor Forbes' report on the electrical transmission of power the unit is taken at 5,000 horse-power. To generate this power on a fall of five hundred feet about 120 cubic feet of water per second would be required, which would be carried by a pipe four feet in diameter with a velocity of between nine and ten feet per second. The pipe would have a mean thickness of five-eighths of an inch, and would weigh 392 lb. to the foot, including an addition of twenty-five per cent. for joints, etc. The total weight would be $262\frac{1}{2}$ tons, and the cost at 20*l.* per ton 5,250*l.*, to which must be added 2,500*l.* for carriage to the site of the works, and 600*l.* for laying, making the total cost of the pipe, 8,250*l.*

A turbine to generate 5,000 horse-power would cost about 6,000*l.*, and 750*l.* might be added for a proportional share of general expenses, making the total cost of the installation 15,000*l.*, or 3·00*l* per horse-power.

The annual cost might be reckoned at—

	£
Interest 4 per cent. on 15,000*l.*	600
Maintenance	600
Depreciation 6 per cent. on 6,000*l.*	360
Total ...	1,560

or 0·312*l.* per horse-power.

The above calculations are for units of 5,000 horse-power, but for most purposes much smaller units would be preferable, and even for the electrical transmission of power I am inclined to doubt whether so large units would be advisable. Professor Forbes' calculations show that the principal item in the cost of transmission is that of the conductors, which is independent of the size of the unit of power, and that the increase in cost of the dynamos and transformers involved in the use of smaller units would not greatly increase the total cost per horse-power.

A pipe two feet in diameter, with a velocity of ten feet per second, would carry thirty-one cubic feet of water per second, and would have an effective head of 476 feet, and generate 1,230 horse-power.

Its mean thickness would be three-eighths of an inch, its weight per foot 110 pounds, its total weight 79 tons, and total cost, including laying, about 2,500*l*. The turbine would cost 1,600*l*., and the total cost of the installation would be about 4,400*l*. for twelve hundred horse-power, or 3·67*l*. per horse-power.

The annual charge would be—

	£
4 per cent. on 4,400*l*.	176
6 per cent. on 1,500*l*.	90
Maintenance	200
Total ...	466

or about 0·39 per horse-power.

It is clear that whatever units were employed the capital cost would not exceed 4*l*., or the annual charge about ten shillings per horse-power.

In a former note on this subject submitted to the Government of Madras, I advocated the use of Pelton wheels as the prime-movers for the generation of power. The Committee's discussions appear to have established the conclusion that these machines are not, in their present form at all events, suitable for electrical work on a large scale, owing to their want of regularity in speed and the fact that they work on a horizontal axis; the first defect I have no doubt might be got over by the use of an appropriate governor, the latter is fatal unless the machine could be modified so as to work on a vertical axis. In the estimates given above it has, therefore, been assumed that horizontal turbines will be used, but for power to be used on the spot and for purposes for which the extreme regularity of speed required for electrical work is not essential, it might be possible to use the Pelton wheel, and, if so, its simplicity and cheapness would be important advantages.

The calculations of cost given above refer to the maximum power of each motor; as the latter would probably never be worked up to its full power for more than a portion of each day, longer or shorter according to the work to be done, the real cost per actual horse-power would be somewhat greater than that indicated by these calculations. For example, the annual cost of a twelve hundred horse-power machine is calculated at 466*l*. If such a machine worked for ten hours daily at an average rate of a thousand horse-power for three hundred days in the year, the annual cost per horse-power at the site of the works would be 0·47*l*., and the cost per horse-power hour (the most accurate way of stating cost) would be about one six thousand four hundredth part of a sovereign or about one four hundredth of a rupee. The cost of a horse-power hour delivered electrically at Madras, Trichinopoly, or Madura would be one-seventieth, one one-hundredth, or one one-hundred and thirtieth of a rupee.

Inasmuch as the cost of steam-power at any one of these places is certainly not less than a tenth of a rupee per horse-power hour the highest of these rates would leave an ample margin of profit while the price at the site of the works would be so small as to offer every encouragement to the establishment of factories, even at a considerable cost for carriage of raw material and manufactured products.

The question of how far Government should be connected with the operations for the development of this power will need careful consideration. It must, in any case, construct the service reservoir and regulating works for the distribution of the power to the different prime-movers, unless the whole power is to be leased to a single speculator, a course which the Government will probably be unwilling to adopt; but the cost of these works, the designs for which can be drawn up by the local Public Works Department, will be trifling, probably not more than Rs. 20,000 for the first ten thousand horse-power and one rupee per horse-power for subsequent additions. On the other hand the Government will probably be unwilling to take any part in the transmission of the power to a distance or in its utilization for industrial purposes, and will either construct the pipes and prime-movers and lease the power derived from them, or lease the water direct from the service reservoir leaving the lessees to utilize it as they please.

A charge of sixty rupees in the former case or of thirty rupees in the latter per million cubic feet (with five hundred feet fall) would give a substantial addition to the returns from the Periyár and be almost unfelt by the users of the power. There would be no difficulty in controlling and recording the water used by such motors so as to enable the charges to be properly levied.

It is stated in the report of the Committee that it is proposed to modify the designs of the Periyár sluices so as to avoid the necessity of shutting off the water entirely for examination or repair of the head works. This is a most important point and the alteration will not add more than five or six thousand rupees to the cost of the sluices.

In the note submitted to the Government of Madras to which allusion has been already made, I remarked that having in view the progress made of late years in the electrical transmission of power, it was by no means certain that it would not be possible in the immediate future to utilize the power of the Periyár water for the lighting of Madura, Trichinopoly, or even Madras itself.

The information supplied to the Committee by Professor Forbes shows that this anticipation was in rear of the facts rather than in advance of them.

No. 3.

Preliminary Memorandum by Professor UNWIN, F.R.S., dated 20th June 1893, on the Periyár Project.

The data given me are that there is a supply of 600 cubic feet of water per second all the year round with an available fall of 1,200 feet. This would yield 60,000 effective horse-power. The only drawback mentioned is the stoppage of the flow for a fortnight annually for examination and repair of the tunnel and head works. This difficulty might, perhaps, be met by a service reservoir. For many applications the stoppage would not be a serious difficulty.

The first question is whether the fall should be utilized as a whole or in parts. With twelve hundred feet fall the pipes would be heavy. If the fall is divided the cost of machinery is increased. On the whole, I should suppose it best to divide the fall into two parts of six hundred feet each. I understand the slope of the ground to be about 1 in 4. Then for a fall of 600 feet the pipes would have a length of 2,400 feet.

The probability is that it will prove economical to make the pipes as large as possible. In America steel pipes of four and five feet diameter have been used under large heads. I think a four-foot steel pipe, double riveted for the lower part, and with transverse joints riveted up from end to end, would be suitable. With a larger pipe the flexibility gives trouble by causing leakage at the joints. I think the pipe should be laid in a trench and covered with earth to diminish the effect of changes of temperature which is liable to rack the joints and cause leaks.

Such a pipe would have an average thickness of about half an inch and a maximum thickness of five-eighths of an inch. It would carry 3,600 effective horse-power on 600 feet fall, and it would weigh about 280 tons. None of these quantities seem impracticable.

The pipe might supply two turbines of 1,800 horse-power each. Under the conditions any type of turbine might be adopted.

Generally for such a large quantity of water a pressure turbine is cheaper than an impulse turbine for equal workmanship and similar adjuncts. But probably conditions of speed imposed by the driven machinery may make it desirable to adopt some form of partial admission turbine. Girard turbines, like those at Terni, would be suitable, or, perhaps, tangent wheels could be more cheaply constructed, for a large power in the conditions at Periyár. Either form permits good speed regulation by a governor.

The Pelton wheel is suggested in the Public Works Department memorandum. But there is no experience in the use of Pelton wheels for so large a quantity of water. I have no reason for thinking that they would cost less than other forms of turbine in the conditions at Periyár. The Pelton wheel is most suitable when used with a single nozzle of small size. If a Pelton wheel of 1,800 horse-power had a single nozzle it would need to be 17 inches in diameter. If it had two nozzles they would have to be 12 inches in diameter each. It is true that Pelton wheels with multiple nozzles were proposed for Niagara, but the regulating arrangements were very crude and I am not aware that they have been tried. They do not seem to me to be so suitable or likely to be so efficient as other turbines.

The efficiency may not be important at Periyár with regard to saving water, but it is important in diminishing the cost of the turbine supply pipes.

Without more knowledge of the country, and the way in which the power is to be applied, it is impossible to make any but the roughest estimate of the cost of the hydraulic power. Further, the cost of transporting the machinery up-country and the probable cost of the excavation is not known to me. But I should think very possibly the cost might be between 5*l.* and 10*l.* per horse-power utilized (capital cost), or, I suppose, between 80 and 160 rupees per horse-power. That is for canals, pipes, turbines, and necessary buildings.

In any case, it appears that power can be obtained cheaply as to capital cost if any application can be found for it. I am disposed to think that the cost of the power would be a small fraction of the cost of electric machinery and transmission for applying it. Hence the problem at the Periyár is essentially a problem of finding an application for a very large quantity of power. The hydraulic part of the problem is the least doubtful and the least difficult. The distance of the site of generating the power from places where it can be easily applied is the most serious obstacle to be met.

No. 4.

Report (Revised) of Professor GEORGE FORBES, F.R.S., on the cost of developing the Water-power obtained from the Periyár Irrigation Works in the Madras Presidency, dated 7th June 1893.

Having been asked by the Committee to lay before our next meeting a report on the cost of the electrical part of these works, including the generation of electric current, and its transmission to certain points as yet undecided upon, and its utilization at these points, I have considered the matter very carefully, and, on attempting to make estimates, I have been met by the difficulty that there are many data about which I have no information. It is natural to suppose that the

machinery will be made in this country, and will be shipped out to Madras, from which point it will be carried probably by railway. If a railway be constructed over the distance from Madura to the Irrigation Works, this cost of transport need not be great; but if a preliminary plant has to be put down for a limited utilization of power, the cost may be considerable. I have no data as to the cost at which a pole line can be established for long distances to carry the large conductors necessary. If time had permitted I might have been able to confer with the telegraph department and get out accurate estimates in accordance with the requirements of the case. As it is, my estimates on these heads may be considered as purely approximate. It will be seen, however, that if we work on the lines I suggest, the cost of copper in the line is the principal expense and other matters are of comparatively small importance.

Conditions to be fulfilled.

The fall which will be utilized is sufficient to develop about 50,000 horse-power on the shafts of the turbines. The first proposition is that this water-power should be developed by means of separate turbines, each of 5,000 horse-power. If smaller units be taken the cost per horse-power will be greater. The most successful working will be obtained from turbines with a vertical shaft, driving dynamos on the same shaft, each dynamo being of 5,000 horse-power. The points to which the electricity has to be carried by conductors vary from 80 to 350 miles. The purposes for which the electricity can be used are various. First, it can be used for the electric lighting of Madura, Trichinopoly and Madras, and possibly other places. This refers both to arc and incandescent lighting—arc lighting being suitable for open spaces, incandescent lighting being suitable for interiors, but being more costly. The electricity conveyed to a distance may also be converted into motive power for driving factories. It is possible that such factories might be attracted by cheap power to sites about 100 miles north of the irrigation works, and the same distance to the south-east, and perhaps in other places. The cheap power might attract cotton mills, and might start new industries, such as the refining of metals and extracting them from their ores.

Among these the production of aluminium by electrolytic processes immediately suggests itself, such processes having been successfully worked both in Europe and America. The uses to which aluminium is put are, at present, limited; but there is now a great effort being made to introduce it into several manufactures, and it is not impossible that the demand may increase considerably. It is worth pointing out the fact that the electrical conductivity of aluminium is very high, being twice as great as copper for equal weights of metal. Thus, if aluminium could be produced at a cost of 1*s.* per pound it would be possible to compete with copper for electrical purposes. I have not the data to permit me to say with certainty whether this is possible or not, but information will doubtless be forthcoming, on the authority of Professor Roberts-Austen. A good deal has also been done in the production of other chemical substances by electrical action not in the domain of metallurgy alone.

In all these cases a continuous current of low electric pressure is required, whereas the current which is transmitted to a distance must necessarily be at high pressure. The transformation can be cheaply effected by using high pressure current to drive a motor, and having on the same shaft a low-tension generator of electricity, but there are several other methods concerning which I will report more fully at the proper time.

A field for the utilization of motive power developed by electricity which promises to be very considerable is that of electric traction. Nearly every city in the United States has its street cars or tramways worked by electricity, and several of the principal steam rail-roads have put down electric locomotives especially for dealing with the local work in their shunting operations with heavy freight trains, and for this purpose very powerful locomotives have been constructed. It is worth considering whether the demand for tramways in Madras is sufficiently great to make it likely that a development in this direction would be important.

The question is also well worth consideration whether the railways in the Presidency south of the town of Madras might not be advantageously worked by means of electric locomotives.

These being the general conditions that required to be fulfilled, I will now state the character of the machinery which seems to me best suited for carrying out these objects.

Character of Machinery.

The first point to be considered is the electric pressure at which the current is to be carried to the distant points. The higher the pressure the cheaper are the conductors required for transmitting the current; and since, in these cases of lighting and power transmission, the cost of conductors is one of the largest items of expense, it becomes a matter of the utmost importance to reduce this cost as far as possible, and this can be done by increasing the electric pressure to the highest limits which we can safely recommend.

The experiments of 1891, between Lauffen and Frankfort, showed that it was perfectly feasible to use 20,000 to 30,000 volts by means of overhead conductors. There were certain difficulties met with which we now know and appreciate, and which will always be avoided in the future. The Oerlikon Company, who were engaged in that experiment, are now putting

down a line 43 kilometres in length for an electric pressure of 40,000 volts. At Niagara Falls the electric pressure which we propose to adopt is 20,000 volts in the first place, with a possible increase as the work proceeds. I should say that, in the case of India, where the atmospheric conditions are favourable rather than otherwise, it would be safe to contemplate the employment of 30,000 volts, or perhaps even 40,000, in the first instance, with overhead conductors. Such a system seems possible when we consider that the chief trouble in the higher latitudes with which I have hitherto had to deal arises from the effects of sleet and snow, and also that in the regions where these overhead poles will be set up, disastrous cyclones are not to be seriously feared. This is the cheapest way in which the line could possibly be laid.

Coming now to be generation of the current, the first thing which has to be decided is whether we shall adopt the continuous or the alternating current. The disadvantage of the former is that it has hitherto been impossible to construct a continuous current dynamo of high electric pressure successfully. This arises chiefly from the fact that a commutator is necessary in this class of machine. A second disadvantage of the continuous current is that there are no means of transforming the pressure without the use of moving machinery. It has sometimes been proposed to obtain a high pressure by connecting, in series, a large number of continuous current dynamos. For example, it has been proposed that each 5,000 horse-power unit should consist of 20 dynamos in series, each of 250 horse-power, giving 1,000 volts, making a total of 20,000 volts. No sound engineering scheme on these lines has been worked out. The expense is enormous, and the danger of handling such machinery would be very great indeed. With the alternating current, on the other hand, it is possible to generate the current directly at the extremely high pressures, which make transmission to great distances possible and economical; it is also possible to generate the current at low pressure, and then, by means of a transformer, to convert it into a current of high pressure for transmission over the line, and at the far end the pressure can be again reduced by a stationary transformer, and led into workshops, or elsewhere, or used for lighting purposes, at the moderate pressures which experience suggests. An alternating current dynamo is also about 40 per cent. cheaper than a continuous current machine of the same capacity, when dealing with large amounts of power.

Whether we consider the matter from the point of economy, safety, or certainty of uninterrupted supply, the alternating current has immeasurably the advantage. I could speak at much greater length on this point if thought desirable, but the point has been so universally conceded by the most experienced engineers, that it hardly admits of argument.

Assuming now that the alternating current is to be used, we must settle whether it is to generate current in a single phase, in two phases, or in three phases. The single phase alternating current is admirably adapted for all lighting purposes. Synchronising motors also work with a very high efficiency, but they require to be started mechanically so as to attain the synchronising speed before being put into circuit. Numerous alternating motors have been made with a single phase which start automatically, but hitherto they have not been largely developed, chiefly because there has been so little demand. Two-phase and three-phase motors start perfectly well on full load, and are quite as satisfactory as continuous current motors for ordinary workshop practice, and will serve for driving tramways or locomotives. They can be stopped, started, and reversed with the utmost ease. They have no commutator, nor collecting rings, on the revolving part, which is completely detached from the rest of the machine except at the bearings. The disadvantage of these multi-phase motors is that they require more than two wires. This is certainly a defect in distribution through a town, or in application to electric traction.

When alternating currents are being used for transmission, it is probable that the best way of using the power for traction purposes is to convert the alternating current into a continuous current at the place where it is used, by means of an alternating current motor driving a continuous current generator. Special machines have been constructed for this purpose which combine the motor and generator parts into one armature, an ordinary continuous current machine being used with insulated rings fixed round the commutator, four or three of them according as we are using a two-phase or a three-phase current brushes being fixed to rub on these rings as they revolve, the rings being attached electrically to commutator bars at equal distances round the periphery of the commutator. The two or three-phase currents being passed through these rings to the armature, cause it to rotate, and the ordinary brushes of the continuous current machines take off continuous current, which serves to excite the field and which may be used for any purpose. Such machines have been constructed largely by Schuckert of Nurnberg, and to a certain extent by the two great American competing manufacturers of electrical machinery.

It appears, then, that the alternating current, either of one, two, or three phases, can be transmitted so as to develop power for motive power and for electro-chemical operations. Certain advantages have been claimed for the three phases. It has been said that the cost of copper in the conductors is less than with two phases. It has also been said that the turning power given to a motor is more uniform with three phases than with two. These claims are untenable.

It has also been said that the three-phase system requires only three wires and that the two-phase system requires four wires. This is not true. The two circuits of the two-phase system may be worked with a common return wire, and when this is done the copper required is less even than with three phases.

The three-phase system has the great objection that the three circuits must be inter-connected. This gives rise to a great deal of trouble in regulating the current, and also in testing the system for faults, and correcting these. The three circuits can never be at the same pressure, unless they are all loaded equally, and this makes the use of the system impossible for lighting purposes. I have made a number of tests on this point which I can lay before the Committee, if desired. The single-phase and two-phase systems are free from these objections, and therefore I give them the preference.

The only question now is whether the single phase or the two phase is the best. For many reasons, I should be inclined to say that a single phase was the best, but the two-phase machinery develops two totally distinct currents, passing through different circuits, each of which can be regulated independently. It can also work multi-phase motors, the advantage of which has already been stated. The two-phase machine gives a larger out-put for the same weight of machinery than the single phase. For these reasons, I would, for general purposes, prefer the two-phase system; but this must depend largely on the character of the uses to which it is to be applied. If the circumstances are such as to yield readily to the adoption of a single-phase current for all purposes, I would be inclined to give it the preference. In the meantime, I propose to deal with the question as if we found it advisable to use two-phase machines, as this is more likely to prove to be the case.

Having now decided that alternating current, with 30,000 or perhaps 40,000 volts, and two phases, would be generated, it becomes necessary to consider what should be the frequency of alternations. This is a matter to which I have given great attention in the past year. I find that, for motive-power purposes, the lower the frequency, the better is the result down to about 10 periods per second; but when the current has to be used for electric lighting, whether arc or incandescent lamps, these low frequencies are not available. It appears, then, that by using a frequency of 50 we can work both arc and incandescent lamps, but the efficiency of our motors is sensibly reduced. I content myself at present with stating this result generally, instead of devoting, as I might, considerable space to showing the data on which I have arrived at this very definite conclusion. With any frequency under 50 periods per second arc lamps are found to flicker; with any frequency under 30 periods per second incandescent lamps are found to flicker disagreeably. If the chief use were for power purposes it would clearly be desirable to have the motors working at the greatest efficiency; and in this case I would recommend the adoption of a low frequency, somewhere about 10 or 15 periods per second, and the lighting would then be done, either by means of motors driving electric generators, or by means of some commutating machine, possibly like the one to which I have already referred. It seems to me probable, in the present case, that a very large amount of electricity might be used for the electric lighting of Madras, and if this is the case it might be best to put down the generators of such a character that they would do the lighting at the cheapest rate, and therefore have a suitable frequency. Motive power could still be efficiently supplied from these generators, although the efficiency of the motors would not be so high, and might only amount to perhaps 85 per cent.

On the whole, then, it might be assumed, for the present purposes, that we shall employ a current with a frequency of about 50 periods per second.

Since the pressure which we shall employ on the line is at least 30,000 volts, it becomes a question whether this ought to be generated directly in the dynamos, or whether the dynamos should give us a current of lower pressure, transformers being added for raising the pressure before the current goes into the line. This last method has been generally considered to be essential for very high pressures, but the additional expense of providing transformers is very great, the cost of transformers amounting in a number of estimates which have been before me to as much as the cost of the generators. If the dynamo be revolved about a vertical axis, and if the armature be fixed and the field magnets be made the rotating part, it becomes as easy to insulate the dynamo as it is to insulate a transformer, and the reduction in cost is very great. We thereby attain, also, an increased efficiency of the whole plant, and we avoid all trouble of introducing the extra self-induction which is involved by the employment of a step-up transformer. This design also enables us to put very considerable momentum into the revolving part, which serves to take up the irregularities due to the varying consumption of power in the moments while the turbine governor is adjusting itself to the varying load.

So far as it is possible to form a judgment without having fuller details of the purposes to which the transmission plant is to be applied, I would say that the above type of machine is what is required, having the following characteristics:—5,000 horse-power, vertical shaft generating 30,000 or 40,000 volts direct, frequency 50 per second, two phases. Such a machine can be got out at a remarkably moderate figure, and I can speak with confidence on this point from having had tenders for dynamos of this power from a number of different firms in Europe and America.

The cost of this dynamo may be taken at not over 6,000*l*., but I find it impossible, at present, to estimate the cost of transport and fixing; nor can I estimate the cost of buildings until the designs of the turbines are submitted. These are all points which must be considered in detail when it is resolved to take further steps in the matter. The cost of transformers of 1,000 horse-power or over may be taken as certainly not over 1*l*. per horse-power, and I am of opinion that they ought to be constructed at half this price. The principal cost of the whole of this plant would lie in the line, owing to the great distances to which the current has to be carried, and to this point I shall now give some consideration.

The Line.

It is quite hopeless to deal with this project except by means of an overhead construction of the line. In many cases, depending on the climate, where heavy snow falls, sleet, and violent cyclones are encountered, an overhead construction is certain to lead to discontinuity in the service, but from what I have been able to learn of the climate in which it is suggested to put down this plant, there will be no serious trouble from this cause. I would therefore propose to put down a line of poles. These may be either of iron or of wood, in the latter case they should be made **A** shape for strength. It may be well, in considering the cost, to suppose that the line is laid out in units of 5,000 horse-power, but in some directions a much larger amount of power can be taken, and the actual cost in the poles will, in these cases, be less.

In the meantime I assume a set of poles for each 5,000 horse-power unit. The poles will be provided with special insulators, of which I can give details when required, embodying everything that has been learnt by past experience as to the troubles that have to be got over in this form of construction, and about the successful action of which there cannot be the slightest doubt. By this method of construction, in fact, I would have no hesitation in going up to an electric pressure of 40,000 volts, and this it would be most desirable to use in case it is proposed to go so far as Madras, whose distance from the irrigation works is 350 miles. It will be well to consider the cost of 40,000 volts carried to a distance of 350 miles.

In order to find out how much copper must be put into the conductors to give the most economical results, it is necessary to tabulate the results with different densities of current, and to compare the money loss in power wasted as heat in the conductors with the interest on the capital sunk in copper. It is necessary to select such a current density that, by a slight increase or decrease in this density, the additional gains and losses owing to difference in power wasted and in interest on capital sunk shall be equal.

If, however, there is no great prospect of so large a demand arising as to utilize all the available power it may be worth while to deliberately waste a considerable amount of horse-power, at a cost only of putting in turbines and dynamos, and wasting this power on the line by using much lighter conductors. In this way we shall arrive at a greater economy on the limited output, and I will work out the figures for the line to Madras.

The difference between these two ways of looking at the problem is this: in the one case we take the value of a horse-power as the selling value at the point where it is delivered; in the other case as the cost of production at the hydraulic works. It is extremely unlikely that the cost of this production of power would amount to more than 15*l.* per horse-power, which, at 10 per cent. per annum, would mean 30*s.* a year for the cost of producing a horse-power.

Having reference to what has now been stated, it will be best to examine what will be accurately the actual cost of the line at different densities of current on the long distance of 350 miles to Madras, assuming an electrical pressure of 40,000 volts. Accordingly I have computed the following table, in which the first column indicates the mean density of current reckoned in amperes per square inch. In the second column is given the cost of the copper per horse-power generated, the price being taken at 50*l.* a ton. The third column gives the horse-power that is lost on the line, and the fourth the remaining fraction of a horse-power that is available. The fifth column gives the cost of copper per horse-power delivered, and the sixth and last column gives the amount of horse-power that has to be generated at hydraulic works in order to deliver one horse-power at Madras:—

D.	Copper per horse-power generated.	Horse-power lost.	Horse-power left.	Copper per horse-power delivered.	Horse-power to be generated per horse-power delivered.
	£			£	
100	70	·08	·92	76	1·1
200	35	·16	·84	42	1·2
300	23	·24	·76	30	1·3
400	17	·32	·68	25	1·46
500	14	·40	·60	23	1·66
600	12	·48	·52	23	1·9
700	10	·56	·44	22·7	2·3
800	9	·64	·36	25	2·8
900	8	·72	·28	28	3·5
1,000	7	·80	·20	35	5·0

This table will be useful for general reference when we have obtained accurate data as to the cost of hydraulic works. The cost of the line, as indicated above, includes by far the greater portion of the total cost of the electrical plant. The electrical item of next importance is the cost of poles and insulators, which, for each unit of 5,000 horse-power, I have taken at 90*l.* a mile, being 1*l.* per pole and 2*s.* 6*d.* per insulator with its attachments, and I have taken 60 poles to the mile. It is probable that in dealing with larger amounts of power the cost will come out somewhat less. It is impossible to fix upon the best density of current to employ until we know the

cost of the hydraulic part of the works, because, as will be seen in the last column, when we reduce expenditure on the line we are increasing the amount of hydraulic power that requires to be developed. I will take a single case to illustrate the manner in which this table can be applied. Let us assume that a density of 400 amperes per square inch should be the most economical value. In that case we can include the main features of expense in the electrical part of the design. As I have stated above, the cost of a dynamo of the type which I have recommended would come to 6,000*l*. for a 5,000 horse-power unit, and the cost of a transformer I will take at 1*l*. per horse-power, although I am quite confident that this is considerably in excess of what we shall find in practice. I do not know how much to allow for cost of transport and erection, and that will be dealt with when the question of more detailed estimates arises. At that time also the small additional electrical appliances, such as switch boards and measuring instruments, may be considered.

The total cost of the principal parts of the electrical plant come out, on the assumption of a density of 400 amperes per square inch, as follows:—

	£
Copper on the line	25·0
Poles and insulators	6·3
Dynamos for 1·46 horse-power	1·75
Transformer for 1 horse-power	1·0
Per horse-power delivered, total ...	34·05

This is the cost for one horse-power continuously delivered at Madras. If we were dealing with the *lighting* of Madras only, the cost of line would refer to a *mean* (or more exactly the square root of mean square of current) output of one horse-power which would probably involve a maximum four times as much. The cost of dynamos and transformers would then have to be multiplied by four and the total capital would be 42·3*l*. for a *mean* output of one horse-power. This way of looking at it makes the electrical cost much more favourable when compared with steam, as the irregularity of lighting hours makes a steam plant very expensive to run.

To find the annual charge, it will be noticed that the copper conductors are permanent value, and it is sufficient to make a charge of 4 per cent. interest on this, while on all the rest of the plant we should make a charge of 10 per cent. for interest and depreciation. This gives the following annual charges:—

	£
Copper conductors	1·0
Poles and insulators	0·63
1·46 horse-power dynamos	0·18
1 horse-power transformers	0·10
Per horse-power delivered ...	1·91

This is for a continuous service. If the maximum demand were four times the mean, the cost would be 2·75*l*. per mean horse-power per annum, and during all the daytime most of this power could be diverted to other purposes.

I have taken this case of transmission to Madras as being likely to be a crucial case to determine whether a further consideration of the question is necessary, because it seems possible that in Madras there may be created a large demand for electricity both for the lighting of the houses and streets and also for working electric tramways. In the previous part of the report where I dealt with a distance of 100 miles, I assumed that we were working with a pressure of only 30,000 volts, but if 40,000 volts can be used for Madras, it can equally well be used to the shorter distances, and a corresponding economy would be thereby introduced.

It will now be asked whether I can undertake that these results can positively be accomplished. With regard to the cost of dynamos, I have gone at considerable length into a statement of the type of dynamo which I would recommend, and my principal object has been to so specify it that we shall be able to obtain such a dynamo at a moderate cost, and since the estimate which I have given is founded on estimates that have been given me for somewhat similar dynamos by a number of manufacturing firms, and as a percentage has been added to cover the extra cost of going to an insulation which will stand a pressure of 40,000 volts, I have no doubt that the cost given for the dynamos is well within that which we should be able to accomplish.

As to the cost of transformers, my estimate here is again in excess of certain estimates which have been received by me for another work where the transformers are built for large powers.

Concerning the price of poles and insulators, I have no hesitation in saying that in any country that I have had to consider in this connection, the work could be done at the price which I have named; but I have not the necessary information with regard to India to enable me to say with a certainty whether it is the case there also. All the machinery hitherto referred to, dynamos and transformers, can without a question be built so as to generate and utilize directly the electric current generated at the considerable pressure of 40,000 volts.

With regard to the line, I would not have any hesitation in saying that this would also be satisfactorily done if I knew that there were no special climatic conditions which may interfere with it. So far as I am aware, there are none such, and I therefore feel the utmost confidence that the line can be carried at the above pressure with freedom from interruption in the supply and with ordinary precautions there will be no danger. Since, however, as I have already stated experiments are at this moment being made in Switzerland, where a line is being tried over a distance of 43 kilometres and using a pressure of 40,000 volts, it will be interesting to follow the progress of this work, and as I have been promised an early account of the results, this information will be available and will be of considerable utility to us. I ought to mention that in the project for utilizing Niagara Falls I am recommending the adoption of a pressure of only 20,000 volts for transmission to Buffalo, and I am well aware that in doing so I am subjecting myself to the accusation of timidity in not wishing to go to a higher pressure. There is no question of timidity in this. I consider that for the 15 miles of distance which have to be traversed, the 20,000 volts giving, say, a loss on the line of only 3½ per cent. is amply sufficient; and it is more with a desire not to lead people to suppose that we are going to unusual pressures than for any other reason that I have not adopted a higher pressure. The manufacturing company which has had most experience in this direction proposed a pressure of 25,000 volts even for this short distance, and another electrician who has proposed using the continuous current in a manner, however, which would be quite unsuitable, has prepared his plans for a pressure of 20,000 volts, though every one with practical experience must admit that the danger in working a continuous current at this pressure would be very considerable.

It would have been possible for me to have gone considerably more into the details as to the methods which I would propose to adopt to make such a system as I have sketched out successful, but I feel that at the present stage of the enquiry what I have said is amply sufficient if the Committee will take it from me that I have naturally had occasion, in the course of my other professional work, to consider these details very thoroughly, and that generally the data from which I have worked out the cost above are such as would be conceded to be trustworthy by the engineering profession generally.

As to the uses to which such a supply of electricity could be devoted, this question will naturally come up for consideration by the Committee later. There is, first, the possibility of attracting large industries to places within 100 miles of the works. Again there is the electric lighting by both arc and incandescent lamps in Madras, Trichinopoly, Madura and elsewhere. There is also the field of electric traction, including, partly, tramways in the large towns, and longer tramways connecting outlying villages with towns. I have already alluded to the further possibility of working all the railways in the Presidency south of Madras by means of electricity, these being now worked by steam.

It seems quite clear that up to the distance of 350 miles, that is, up to Madras, it will be possible to supply electricity at any low pressure suitable for electric lighting or for motive power at a cost of not more than 4*l.* per horse-power per annum, including all costs with a margin for contingencies.

No. 5.

Report by Professor ROBERTS-AUSTEN, C.B., F.R.S. Water-power at the Periyár Irrigation Works.

COST OF EXTRACTION OF ALUMINIUM.

The metallurgical questions which I have mainly to consider are those relating to the possibility of obtaining metallic aluminium by electrical energy, falling water being the motive power.

Mr. Chatterton's memorandum, which forms the basis of the inquiry entrusted to the Committee, states, page 3, that in the southern part of India there are numerous deposits of corundum which have long been worked as a source of emery. They occur in the districts of Salem, Coimbatore, Bellary, North Arcot and Kistna, in the Native State of Mysore and further off in Rewah and the Khasi Hills in Assam. I have consulted the authority * cited by Mr. Chatterton as describing the Indian deposits of corundum, but cannot find any analyses of the materials. I have analysed a specimen of corundum from the Salem district

* "Manual of the Geology of India," Part III; "Economic Geology," by V. Ball, London, Trubner & Co., 1881.

obtained from the Geological Museum of Jermyn Street, and find it to be of a high degree of purity, but I have no means of ascertaining whether it is an average sample. It is added that it is not absolutely certain that these deposits would be capable of yielding the 40,000 tons per annum which it is estimated will be required. It is also stated that 10*l*. per ton would probably be the maximum price to be paid for it.

I have as yet been unable to obtain either from Sir George Birdwood, or from the Imperial Institute, specimens of the particular deposit which would probably afford the source of aluminium; I am therefore in doubt as to the purity of the deposits generally, or as to the readiness with which the corundum could be reduced by electrical agency. I do not propose at present to give details as to the exact nature of the plant which is to be adopted, but it will probably closely resemble that adopted at the Patricroft works near Manchester, of which elaborate descriptions are available. Attention will therefore be mainly directed to the considerations of such details of cost of production as can be obtained.

First as regards the energy required for the electrical reduction of aluminium.

Mr. Chatterton's memorandum states that in 1890 at Pittsburgh, about 500 horse-power is continuously employed in the production of 375 lb. of aluminium per day. He also quotes from a paper published by Mr. J. H. J. Dagger* in which it is stated that an electrical furnace absorbing 500 horse-power, working Cowle's process, yielded 410 lb. of aluminium in the form of alloy. I am of opinion that the adoption of Cowle's original process, which only yields alloys of aluminium with copper or iron, should not be contemplated, and that it will be preferable to direct attention on the production of pure aluminium, and for this the prominent processes are those of Heroult, of Hall, and of Minet. The best known works for the production of aluminium itself is the "Aluminium Industrie-Actien-Gesellshaft, Neuhausen, at Schaffhausen on the Rhine." The dynamos are furnished by the firm of Escher, Wyss & Co., Oerlikon, near Zurich.

* Report, British Association, 1889, p. 538.

Three dynamos are employed, two of 600 horse-power and one of 300 horse-power. This is probably equivalent to 482 English horse-power and 241 English horse-power respectively. The axes of rotation are vertical.

Great care seems to be directed to the control of the speed of the turbines and dynamos which is known to be an important point in connection with all electrical installations devoted to metallurgical purposes. Each dynamo is of multipolar type, and gives a working current of about 6,000 to 7,000 amperes. The potential is about 30 volts with a speed of about 150 to 200 revolutions per minute.

At Froges, in the Department of Isere, France, the installation is similar in character, and the bath submitted to the action of the electric current consists of alumina diffused or melted in fused cryolite, the native double fluoride of aluminium and sodium. Without going into precise details it may be well to add that in both the Heroult and Hall processes, the bath is either bauxite or preferably pure alumina suspended in fused cryolite, a layer of copper or of iron being sometimes placed at the bottom of the bath when it is desired to form alloys with the liberated aluminium. In the Minet process, on the other hand, the bath which is submitted to the influence of the current contains 30 to 40 per cent. of an artificial fluoride of aluminium and sodium and 60 to 70 per cent. of common salt, the bath being regenerated with pure alumina. The composition of the bath however varies, one proportion being—

1 part cryolite.
2 parts artificial fluoride.
4 ,, alumina.

The cost of horse-power at the Periyár works is estimated by Colonel Pennycuick at Rs. 20 per annum for 24 hours daily. At Pittsburgh it is found that 22 electrical horse-power hours (or 16,412 Watts) are required for the production of a pound of aluminium. Assuming that a loss of 15 per cent. occurs, and that 25·9 horse-power is required at the turbine to produce the 22 E horse-power at the bath, this on Colonel Pennycuick's estimate would cost 1·07 pence (valuing the rupee at $\frac{1}{16}$ of a sovereign).

With reference to this estimate it may be well to point out that Professor Coleman Sillers stated in 1891, with reference to the production of aluminium, that he did not consider it "safe to predicate the value of metal, produced upon anything short of $15 per horse-power per annum, for 24 hours daily, while perhaps $20 per horse-power would cover all contingencies." This would give for 22 electrical horse-power [allowing (as he did only) 10 per cent. loss in conversion], 6 cents, or 3 pence, as against Colonel Pennycuick's 1·42 pence.

A still more recent estimate by Herr Diebl puts the probable cost of energy in the Heroult and Minet processes respectively at a much higher figure as will be seen by the annexed table, yet his estimate for the total cost of a pound of aluminium by the Heroult process is under 2*s*., and for that produced by the Minet process a little over 1*s*.

It will thus be seen that the cost of energy as estimated by Colonel Pennycuick compares very favourably, even if the output of the proposed works should be forced to such an extent as to require a higher voltage.

If the voltage were raised to 20 at the bath, then 35 horse-power hours would be theoretically required to produce a pound of aluminium, and the cost of energy would be raised to 2·23 pence, but the establishment charges might in this way be somewhat reduced. It may be assumed that in a large work the cheapness of the Native labour would counterbalance the increased cost of superintendence, and the two items of cost—labour and superintendence—might be taken at 1½*d.* per lb. of aluminium produced. In consideration of the fact that all appliances would need to be brought from a great distance, it would be well to allow 2*d.* per lb. to meet the charges of interest on capital and for repairs. Chemical stores would be also expensive, and 1*d.* per lb. had better be allowed for this item; and as carbons suitable for electrolytic work at high temperatures have to be exceedingly dense, ordinary charcoal is quite unsuitable. As a safe approximation, based on such imperfect data as I have been able to collect, I should say that suitable electrodes could not be produced under a cost of 2*d.* a pound at the spot.

The estimate therefore will be—

	s.	*d.*
Energy		1·10
Alumina, 2 lb.		6·0
Labour and superintendence		1·5
Interest, repairs, and maintenance		2·0
Chemical stores		1·0
Carbon electrode		2·0
Cost of 1 lb. ...	1	1·6

Captain Hunt's estimate of the cost of producing 1 lb. of aluminium—

	d.
2 lb. alumina (52·9 Al.)	3
1 lb. carbon electrode	1
Chemicals, carbon dust, pots	0·5
22 electrical horse-power hours (water-power)	2·5
Labour and superintendence	1·5
General expense, interest, and repair	1·5
Total cost ...	10·0

Very grave considerations are presented by the nature of the material it is proposed to employ.

Mr. Chatterton allows 1·1*d.* a pound for the cost of the corundum, or if alumina were imported from Germany he places the cost at 20*l.* per ton, or say, 2·2*d.* a pound, and such alumina would not contain more than 50 per cent. aluminium. I believe that this is considerably under-estimated; on the other hand an authority already quoted places the cost of prepared alumina (containing 52·9 per cent. of aluminium) at 1·5*d.* per lb. If the corundum is associated with either much iron or silica, its reduction will present great difficulties. It is not easy to purify aluminium from silicon and iron, and moreover, the presence of much silica in the bath would lead to great loss, as it would decompose the cryolite giving rise to the evolution of fluorine. Much will, therefore, depend on the purity of the corundum and on the readiness with which it can be reduced. In the absence of direct experiment upon these points, I incline to the opinion that it will be preferable to employ artificially prepared alumina rather than the Native mineral.

APPENDIX TO No. 5.

Zeitschrift des Vereines Deutscher Ingenieure Sieger District Meeting, 7th June 1892, 27th May 1893, p. 600.

Manufacture of Aluminium, Hr. Diebl.

Method and raw material.	Cost of 100 lb.	Per cent. of aluminium.	Cost of 1 lb. A 1 in raw material.	Rates for 1 lb. of aluminium yielded.		Horse-power hours for each 1 lb. aluminium.		Value of horse-power hours in shilling, at 0·061 per horse-power hour.	
				60 per cent.	90 per cent.	60 per cent.	90 per cent.	60 per cent.	90 per cent.
1	2	3	4	5	6	7	8	9	10
1. Cowle's, Alumina	27·7	50·0	·554	..	..	..	..	..	..
2. Heroult, do.	27·7	50·0	·554	14·545	..	19·5	..	1·189	..
3. Minet, Cryolite (with chloride of sodium) Alumina	4·536	84·0	·566	13·636	9·090	18·3	12·2	1·116	·744

Method and raw material.	Bye-products with 1 lb. aluminium.			Amount of		Value in shillings.	Total cost of production.	—
	Co.	Cl.	Value.	Carbon electrode.	Coke.			
	11	12	13	14	15	16	17	18
1. Cowle's, Alumina	1·52	..	..	..	..	..	..	..
2. Heroult do.	1·52	..	..	·60	..	·068	1·811	..
3. Minet, Cryolite (with chloride of sodium) Alumina	..	3·87	·445	..	·20	·184	{ 1·361 { 1·049	for 60%. for 90%.

(Signed) J. HANNAN,
Ag. Joint Secy. to Government, P.W.D.

APPENDIX IV.

Extract from letter from the Sub-divisional Officer, Tirumangalam, to the Executive Engineer, Madura Division, dated 26th September 1897, No. 389 (with six samples of limestone).

* * * * *

2. *Sample No.* 1 is from Pandalgudi village, 8 miles due south of Aruppucottai in Ramnad zemindari. Nearest railway station in Tulukuppatti, distance 12 miles (no metalled road). Each local cart carries about 700 to 800 lb. of this stone. Cart-hire is Rs. $1\frac{1}{2}$; cost of quarrying is 8 annas per cubic yard. This limestone is had 3 feet below ground surface and lies in blocks, large and small, varying in thickness from 4 to 9 feet.

Probable extent of bed is about 12 miles long and a furlong width.

Sample No. 2 is from dry lands near Virudupatti village, belonging to Tirumangalam taluk of Madura district. Virudupatti itself is a railway station. Each local cart carries 700 to 800 lb. of this stone. Hire is 2 annas per mile per cart, cost of quarrying is 8 annas per cubic yard. This limestone lies in blocks and almost on ground surface. Its thickness varies from 3 feet to 10 feet. Probable extent of bed is about 7 miles long and a furlong wide.

* * * * *

Sample No. 5.—This quarry is at Karumathur village in Tirumangalam taluk of Madura district. Nearest railway station is Sholavandan. Distance 10 miles (metalled road) and there being the Vaigai river to be crossed. Carts will generally go to Madura Railway station which is 14 miles from the quarry (metalled road). Each local cart carries 1,000 lb. and hire is Rs. $1\frac{1}{4}$ per cart. Cost of quarrying is 8 annas per cubic yard. This limestone is had in small nodular masses and the samples sent are the biggest size available. It is buried 3 feet below ground and is quarried to a depth of 9 feet. Probable extent of bed is about 3 miles long and a mile broad.

* * * * *

3. It may not be out of place to mention that for quarrying limestones from tracts belonging to zemindaris something will have to be paid in shape of seigniorage at 2 annas per cubic yard.

* * * * *

From Surgeon-Major J. L. VANGEYZEL, M.B., F.I.C., F.C.S., Chemical Examiner, to the Chief Engineer and Joint Secretary to Government, Public Works Department, Irrigation Branch, dated Madras, 11th November 1897, No. 1068.

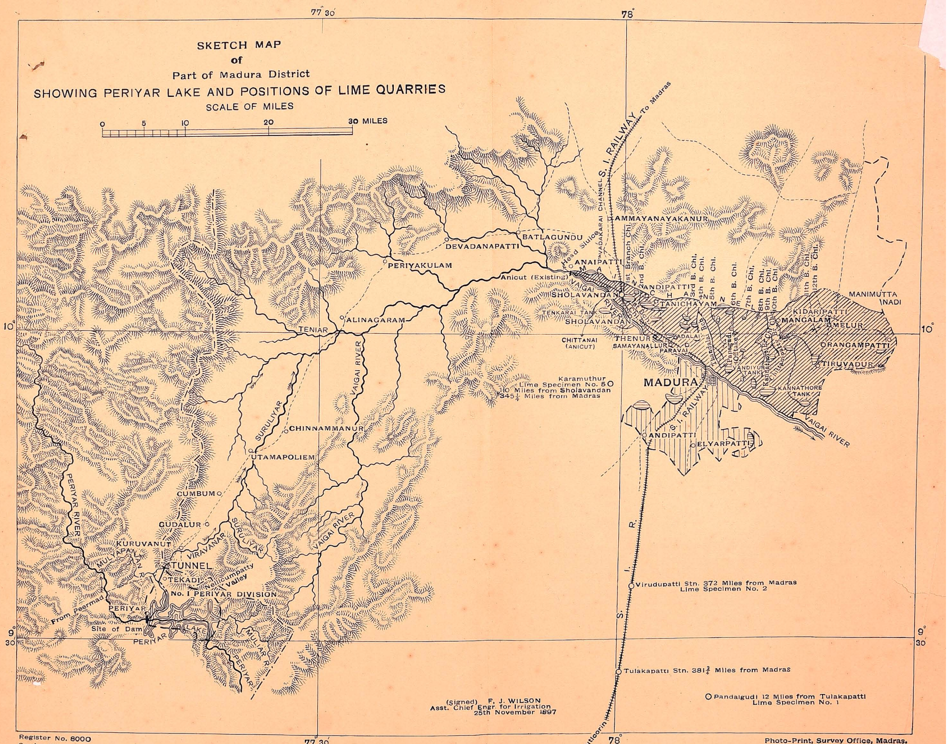
With reference to your letter, No. 351 M., dated 20th October 1897, I have the honour to forward the results of the analyses of the samples of Madura stone and coral. It will be seen therefrom that the Madura stones I and II are almost pure calcium carbonate. The total amount of lime (CaO) present in each of these accounts in round figures for 99 per cent. of pure calcium carbonate in each of the stones. The total carbonic anhydride (Co_2) in each of these, when converted into its equivalent of calcium carbonate, works out at 97 and 98 per cent. of calcium carbonate, respectively.

The other stone and the corals are not so suitable for the purpose which you have in view.

ENCLOSURE.

ANALYSES of three samples of limestones and two samples of coral.

—		No. I stone from Pandalgudi.	No. II stone from Virudupatti.	No. V Karumathur limestone.	No. II coral.	No. III coral.
Moisture	P.C.	Trace.	Trace.	0·806	1·582	0·253
Sand, etc., insoluble in Hydro-chloric acid	,,	0·230	0·330	13·250	1·920	0·670
Ferric oxide and alumina ($Fe_2 O_3 \times Al_2 O_3$)	,,	0·500	0·200	2·300	0·600	0·200
Lime (CaO)	,,	55·328	55·440	45·976	46·984	53·032
Magnesia (MgO)	,,	0·072	0·216	0·432	0·252	0·144
Sulphuric anhydride (So_3)	,,	Trace.	Trace.	0·085	0·532	0·480
Carbonic anhydride (Co_2)	,,	43·000	43·200	35·600	38·800	39·600
Chlorine	,,	Trace.	Trace.	0·022	0·621	0·035
Alkalies, phosphates, etc.	,,	0·870	0·614	1·529	8·709	5·586
Total		100·000	100·000	100·000	100·000	100·000



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Confidential

PUBLIC WORKS DEPARTMENT,

IRRIGATION BRANCH.

PROCEEDINGS OF THE MADRAS GOVERNMENT.

READ the following

Order. No 773 I dated 14 July/04

Ordered that the following -- letter be sent:-

To

The Chief Engr. for Irrign.
with copy of letter to India.

To

No 774 I dated 14 July/04

The Secretary to the Govt. of India,

P.W.D., Irrign. Roads & Buildings

Sir,

I am instructed to submit for the consideration of His Excellency the Viceroy in Council a report by Major A.J. de Lotbiniere, R.E., on the utilization of the Periyar water for the development of electrical energy, and to invite an expression of the views of the Government of India on the -- scheme itself, and the financial -- arrangements necessary for its --- execution.

Appendix 1.

Despd 15.7.04

2. Proposals similar to those now put forward were made as far back as 1892, and in 1893 the subject was -- referred to a Committee composed of Colonel Pennycuick, R.E., and Professors Unwin, Forbes and Roberts-Austen. After the receipt of the --- Committee's report notices were sent to

Appendix 2.

various English and Indian newspapers resulting in numerous applications for power, which Government found themselves unable to entertain, as they were not in a position to guarantee any considerable continuous supply of water throughout the year.

3 In January of the present year the Chief Engineer for Irrigation in his Inspection Notes on the Periyar works again raised the question of utilizing the power available for industrial purposes, and showed how a continuous discharge of 500 cusecs could be safely guaranteed. Government thereupon decided to consult Major A.J.de Lotbiniere whose connection with the Cauvery Power installation qualified him to advise in the matter.

Appendix 3.

4. It will be seen from Major de Lotbiniere's report that he does not propose to utilize the whole power available in the first instance, and only deals with an installation capable of supplying consumers with 10,000 H.P.

5. For an installation of this size it would not be necessary to have the storage reservoir on the plains or the pumping installation at the Lake, referred to in the Notes of the Chief Engineer for Irrigation.

6 An estimate will very shortly be submitted for increasing the capacity

3-P

of the lake by 2,360 million cubic feet, and affording extra escape power, as recommended by Sir T. Higham in his Note printed with G.O. No 420 I d/ 9/3/03.

This extra 2,360 million cubic feet will be more than sufficient to generate 10,000 H.P. during March, April, and May, and its abstraction will simply prevent the extension of irrigation contemplated, but will not in any way diminish the customary supply from the reservoir.

When a larger installation capable of using all the power available is erected, both the reservoir on the plains and the pumping installation will be necessary, for reasons explained in the Chief Engineer's notes.

By omitting the storage reservoir on the plains the water used for power during March, April & May will for the most part be wasted, but for the small installation now proposed this waste will amount to less than 150 cusecs, and it ~~is~~ may be considered expedient to accept this loss for a few years, as the experience gained during the working of the 10,000 H.P. installation will be of the greatest service when the complete installation for utilizing the whole available power is erected.

So far as irrigation is concerned,

6. I am also to point out that the water used for power during the hot

season though not available for irrigation, may be regarded as ~~will have been~~ more profitably employed, both in respect of financial results, and of the ~~further~~ development of the -- industrial resources of the country.

6. With regard to Major de Lotbiniere's estimate I am to observe that while Government are prepared to accept as reasonably accurate the calculated cost of the works, they consider the rates proposed for the sale of power far too low. If adopted, the Project would pay nothing like 5 % and would be in marked contrast to the Cauvery Power installation for delivering 4185 H.P. which paid the Mysore Government ~~16.26~~ 6.3 per cent, besides enabling them to recover their original outlay after 10 years, whilst the Company were saved £ 598,455 in 10 years in addition to becoming the owners of the plant at the end of that time.

Appendix 4 ~~Extract 4~~

7 There can it is believed be no doubt ~~about~~ that the installation proposed by Major de Lotbiniere can be made a profitable concern; ~~paying well~~, but in strongly recommending the scheme for the favourable consideration of the - Government of India, this Government has chiefly in view the industrial developments which are certain to attend the introduction of cheap power in Southern India.

Should the scheme commend itself to His Excellency the Viceroy I am to suggest that Major de Lotbinere's report should be submitted to the Secretary of

4 P

State with a request that an electric expert may be sent out to prepare an accurate estimate on the spot, and arrange for the purchase and erection of the plant.

[illegible]
11/7/4

[illegible]
11.7.04

[illegible] 13.7.04

No. 1020-I
28/11/15 - 580

Appendix I

Report by Major A. J. De Lotbiniere R.E. on the utilisation of the Periyar water power

note

Appendix II

~~Note Report of the~~
Note on utilisation of water-power Periyar Project

A P P E N D I X. 3.

6.80

Extract from the Inspection Notes of the Chief Engineer for Irrigation, for January 1904.

----

x x x

15. 15th January. Reservoir on the Vyravanar.

In G.O., No.434 I, dated 12th April 1902 an estimate was sanctioned for surveys with a view to find a suitable site for a reservoir at the head of the Cumbum valley to supplement the storage of the Periyar Lake. A good many sites have been examined and the one now being investigated would provide a reservoir holding 4,000 million cubic feet, whilst very little would be required for compensation. The cost of the bund, a considerable length of which would have to be of masonry would be heavy, but till a more complete examination has been made of the rock available for founding the central portion of the dam, it would be premature to give an opinion about the suitability of the site.

The investigation should be pushed on more rapidly as it is high time something definite was settled about this very important subject.

The maximum height of the earth portion of the bund should not exceed 60 feet.

x x x

17. 16th - 18th January. Periyar Lake.

Right bank escape and increased storage.

It has for sometime been recognised that there is a very great deficiency in escape power and that with a rainfall similar to that of 1869, the dam would be in danger. This was, I believe, first noticed by the Inspector-General of Irrigation in his Inspection Notes dated 30th January 1897.

Certain proposals were then submitted by the Chief

Engineer for Irrigation in his Note embodied in G.O., No.584 I, dated 29th July 1898, and in October 1902 the Inspector General ordered the preparation of estimates for lowering the right bank escape and weir by 4 feet and fitting the latter with 4' falling shutters.

This arrangement would only answer so long as the F.T.L. was kept as at present.

There can, however, be no question regarding the expediency of increasing the storage capacity of the lake, and proposals for additional escapage should take into consideration the altered conditions which this will involve.

It would not be possible to store more than a small portion of the 10,000 million cubic feet which is the average surplus yearly wasted, but by raising F.T.L. from R.L. 144 to R.L. 152, the capacity of the lake would be increased by 2,361 million cubic feet.

With this change in the F.T.L. it would be -- necessary to cut down the escape channel 8 feet and build a powerful regulator with lift shutters 16 feet in height. The length available is 420 feet and details have yet to be worked out.

The cost would be under 3½ lakhs. Without increasing storage it would be necessary to spend at least a lakh on additional escape power, so that the extra storage will not cost more than 2.5 lakhs, a small amount to pay for water sufficient to irrigate 10,000 acres.

The investment should be eminently remunerative and there seems no reason for indefinitely postponing the work as contemplated by the Inspector-General when he suggested cutting down the existing escape channel and weir 4 feet and providing the latter with 4' falling shutters.

The Superintending Engineer will submit estimates with the least possible delay.

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Power Sch me. After the report of Colonel ---
nycuick's Committee in 1893, notices were sent to --
English and Indian sewspapers inviting tenders for the
utilization of Periyar water power.

Applications were received from various firms, but, as Government was not in a position to guarantee a -- continuous supply of water throughout the year, it was decided in G.O., No.1145 I, dated 4th October 1902, that no concessions could be granted for the present.

In order that the Periyar water may be successfully used for generating power on a large scale, it will be necessary (1) to construct a storage reservoir on the plains as near the foot of the hills as possible, and (2) to increase the storage capacity of the Periyar lake -

(1) Storage reservoir on the plains. Under present arrangements, Periyar water is supplied for irrigation for nine months, and during March, April and May the head sluice is closed.

Without a storage reservoir on the plains, therefore, the water supplied for power during March, April and May would run to waste, and there might be times when it -- would be required for existing cultivation.

It is believed that it will be possible to give a continuous discharge of 500 cusecs, and so the reservoir must be able to hold the amount which would be discharged at this rate during the months of March, April and May, or say 4,000 million cubic feet.

A site for such a reservoir can certainly be found.

(2) Increased storage capacity of the Periyar lake. The present total capacity of the lake is 13,000 million cubic feet, but only half of this amount is available, the other half being below the level at which water can be passed through the head sluice.

The water which, under existing arrangements, could be used for the development of power, is limited to the daily discharge the reservoir could furnish during March,

April and May. To ascertain what this amount is, we have the r registers for seven years and during this time we find that the lowest level of the lake at the close of the irrigation season was 120 in February 1900, which would give less than 1,000 million cubic feet available for use in the lake.

As 4,000 million cubic feet are required to give 500 cusecs during the three months, the necessity for increased storage, or for rendering available for use the lower half of the reservoir, is at once apparent.

I have already shown how we can increase the capacity of the lake by 2,360 million cubic feet by cutting down the level of the right bank escape and building a regulator with lift shutters; so that, with the 1,000 million at present available, we should have 3,360 million against 4,000 million which we require.

The difference, viz, 640 million cubic feet, I propose, we should take from the lower half of the reservoir either by pumping or by making another tunnel at a suitable level.

It may be said I have no right to assume that there would always be enough water in the river to supply the extra 2,360 million cubic feet we propose to store, and that the lake level would never fall below 120 at the close of the irrigation season.

In the year 1898-99, for instance, there was no surplus; but it must be remembered that, owing to the failure of Colonel Pennycuick's equilibrium sluice, there was no regulation till the erection of Stoney's sluice in June 1899 and consequently a great waste of water before that date. What this wastage amounted to it is impossible to say, but -- neglecting it altogether, it may safely be affirmed that if additional storage had been provided, lake level at the end of the irrigation season of 1899-1900 would have stood at 130 instead of 120.

It is therefore practically a certainty, seeing that both 1898-99 and 1899-1900 were exceptionally bad years, that, with effective regulation and increased storage, the

8-121

lake will never again fall as low as 120.

But even if it fell considerably lower, we should still be in a position to supply the 4,000 million cubic feet required by drawing on the lower half of the lake, the contents of which w amount to 7,000 million cubic feet.

It seems to me, therefore, that we are in a position to guarantee with the utmost safety a continuous supply of 500 cusecs, and no more time should be lost in deciding on the best way of utilising this enormous source of power. The electrification of the South Indian Railway immediately suggests itself, but an electrical expert from England should be engaged to advise Government on this point,, and to prepare the estimates for whatever schemes may be decided upon. There is no need to wait for the -- completion of the storage reservoir before commencing the hydraulic and electrical works, which will take a long time to erect. There can be no doubt that any suitable scheme for applying the power will be most remunerative, and the very best advice should be obtained as soon as possible.

The power scheme does not in any way clash with the interests of irrigation. All water used for power will be used for irrigation, and the increase in the capacity of the lake will simply safeguard present cultivation.

The subject is one of immense importance, and I trust my proposals will be favourably considered.

x x x

Fuel cost of at least considerably lower, we shoul[illegible] still be in a position to supply the 4,000 million [illegible] fuel required by offering on the lower half of the [illegible] the contents of [illegible] a return up to 4,000 million units [illegible] Cost.

It seems to me, therefore, that we are in a pos[illegible] to guarantee with the utmost safety a guaranteed [illegible] 000 pounds, and no more time should be lost in consi[illegible] on the best way of utilizing this enormous source [illegible] power. The electrification of the South Indian Rail[illegible] immediately suggests itself, but an electrical engi[illegible] Madras should be engaged to advise Government on th[illegible] point, and to prepare the estimates for whatever sc[illegible] may be decided upon. There is no need to wait for th[illegible] completion of the storage reservoir before conside[illegible] distribution and electrical works, which will take a l[illegible] time to erect. There can be no doubt that any reasona[illegible] scheme for utilizing the power will be most remunerat[illegible] and the very best scheme should be selected as soon [illegible] possible.

The power can be used not as any one almost entir[illegible] independent of irrigation, all other uses for power [illegible] to a low rate of irrigation, and the [illegible] of the land [illegible]

The subject is one of immense importance, and [illegible] my proposals will be favourably considered.

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A P P E N D I X. 4.

98

Extract from a paper on the "Cauvery Power Transmission Scheme".
(Minutes of the Proceedings of the Institution of Civil Engineers - Vol. CLII.)

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The Government shall supply, and the Companies shall take, approximately 4,000 H P. The electrical power of an electric motor is to be taken as equal to the indicator horse-power of the steam-engine it replaces. In the case of new machinery, the power available at the terminals of the motors, in watts, divided by 746, shall represent the horse-power.

The Companies agree to pay the Government the -- following rates per annum for each horse-power:-

First year £ 29; second, third and fourth years £ 18; fifth year a sum which the Government will determine, not to exceed £ 24; sixth, seventh, eighth, ninth and tenth years, £ 10.

x x x

The whole undertaking was estimated to cost the Mysore Government the sum of £ 287,300, or £ 71.825 per horse--power for 4,000 H P. The distribution having since been increased to 4,185 H P., the actual cost has been --- £ 336,267, or £ 80.35 per H P. The total revenue for the 10 years, according to agreement, will be £ 657,045. The yearly maintenace costs are estimated to be £ 11,000, not including depreciation, for which no allowance is being made. Deducting £ 110,000, the estimated maintenace costs for 10 years, from £ 657,045, a total return of £ 547,000 is shown. This is equal to 16.26 per cent per annum. The mine engineers estimate the cost of steam-power at £ 30 per horse-power per annum, which gives the total amount

expended in 10 years for 4,185 H P as £ 1,255,500. If £ 657,045, the cost of the electrical power for that time, is deducted from this sum, it will be seen that the mines have a surplus of £ 598,455 in 10 years, together with the whole of the distribution plant (as per agreement) less 9 years' upkeep of the plant.

x x x